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THE GEOLOGY OF NORTH DAKOTA

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INTRODUCTION

The geology of North Dakota is comparatively simple. The geological formations are not as numerous or of such great variety as in many states, and the strata have undergone but little deformation since they were deposited. They are for the most part practically horizontal or have only a gentle dip. Metamorphism has produced little or no change in the rocks, and, except for the deeply buried granite near the eastern borders of the state, there have been no intrusions or extrusions of igneous material. The rocks are chiefly clays, shales, and sandstones belonging to the Cretaceous and Tertiary periods, overlain in most places by the drift deposits of the Pleistocene. The surface features of about two-thirds of the state are therefore those of a gently rolling to rough drift plain. The flat lacustrine plain of the Red River Valley occupies a strip 25 to 35 miles wide along the eastern border, while west and south of the Missouri River the drift mantle is too thin to affect the topography to any great extent. This large area beyond the Missouri everywhere shows evidence of long-continued erosion, with its numerous stream valleys, buttes, mesas, and badlands.

THE PRE-CAMBRIAN GRANITE

Many deep wells in the Red River Valley have reached granite, and these show that beneath the drift and older formations the valley is underlain by crystalline rock which is probably of Archean age, though like some of the Minnesota granite it may possibly be Keweenawan. The granite is struck at depths ranging from 255 to 470 feet, and its surface is quite uneven. It is overlain in some places by glacial drift, in others by Cretaceous shale and sandstone, and in the northern portion of the valley by Paleozoic strata.

In going from south to north in the valley the granite has been encountered in wells at various depths as follows: Wahpeton, 470 feet; Moorhead, Minnesota, across the river from Fargo, 365 feet; well 7 miles north of Moorhead, 255 feet; Casselton, 20 miles west of Fargo, 455 feet; Grand Forks, 385 feet; East Grand Forks, Minnesota, 325 feet; University, two miles west of Grand Forks, 425 feet; and Grafton, 40 miles north, 903 feet. The well at Rosenfeld, Manitoba, 14 miles north of the international boundary and 11 miles west of the Red River, reached the granite (or gneiss) at 1,035 feet.[1] In the Soldiers' Home well at Lisbon, a few miles west of the Red River Valley on the Cheyenne River, the granite was struck at 785 feet. The Moorhead well, which was drilled by the city in search of water and gas, is notable on account of the distance it went in the granite, the record being as follows: 220 feet of alluvial and lacustrine silt, 145 feet of bluish and greenish shales, with beds of sand, probably Benton, and 1,385 feet of granite and gneiss, thus reaching a depth of 1,750 feet.[2]

THE PALEOZOIC SYSTEMS

During at least a portion of this era the Paleozoic sea appears to have covered North Dakota, and in its waters were deposited the limestones, shales, and sandstones of the Cambrian, Silurian, and Devonian. Two or more of these systems outcrop not far to the north in Manitoba, to the east in Minnesota, and to the south

[1] G. M. Dawson, "On Certain Borings in Manitoba and the Northwest Territory," *Trans. Royal Soc. Canada*, IV, sec. 4 (1886), 85–91.

[2] Warren Upham, *U.S. Geol. Survey, Mono. No. 25*, 1896, p. 556.

in the Black Hills, but they are in this state deeply buried beneath more recent formations. The Grafton well passed through, beneath 298 feet of drift and Lake Agassiz silt, 605 feet of Paleozoic strata, including 288 feet of shale and sandstone, which has been referred to the Cambrian, and 317 feet of limestone, sandstone, and shale, which are believed to belong to the Ordovician.[1] In the deep well at Grand Forks, 40 miles south of Grafton, only one foot of limestone was found just above the granite, showing a rapid thinning of the formations in this direction, due either to inequality of deposition or to erosion. The Ordovician appears to thicken rapidly toward the north, for while at Grafton, as stated above, it is 317 feet thick, 60 miles north at Rosenfeld, Manitoba, it has increased to 700 feet, and is overlain by 192 feet of Silurian strata.[2] On the other hand, these formations thin out toward the west, and at Morden, 27 miles from Rosenfeld and 15 miles north of the international boundary, the Ordovician and Silurian are absent, as shown from the well record. The Dakota sandstone at Morden rests directly on the Devonian beds. In the Morden well, at a depth of 412 feet, 188 feet of Devonian red and gray shales and a thin layer of porous limestone were penetrated, and strata of this age cover a narrow strip of territory lying just west of the Silurian in Manitoba. It is not unlikely that these Devonian and Silurian strata extend south some distance into North Dakota. In the deep well at the Jamestown asylum 19 feet of limestone was penetrated at the bottom of the wells, at a depth of 1,505 feet. The well at LaMoure, about 40 miles southeast of Jamestown, struck a compact gray crystalline limestone with a pinkish tinge at 1,300 feet, and went 28 feet in this rock, stopping at a depth of 1,328 feet. The age of the limestone struck in these two wells is not known, though it is probably to be referred to the early Paleozoic. During the later Paleozoic the region does not appear to have been an area of deposition and probably remained above the sea also throughout a large part of the Mesozoic, since rocks belonging to the Triassic, Jurassic, and Lower Cretaceous or Comanchean are, so far as known, wanting in the state.

[1] *Ibid.*, p. 77. [2] G. M. Dawson, *op. cit.*

THE CRETACEOUS SYSTEM

Dakota sandstone.—The oldest Cretaceous formation in North Dakota is the Dakota sandstone which is reached in many wells but does not appear at the surface anywhere in the state. In the southeastern counties, as well as in South Dakota and elsewhere, the sandstone is the chief source of artesian water. It is a non-marine formation and was deposited either in a large lake or was spread by rivers over their broad flood plains. The Dakota sandstone underlies the entire state, except a considerable portion of the Red River Valley, where it has been removed by erosion (Fig. 1).

A rather fine-grained white sandstone, which is doubtless the Dakota, is found in a number of wells in the Red River Valley at depths ranging from 250 to 400 feet, and in several wells the sandstone was penetrated 100 feet. In southeastern North Dakota outside the valley, the Dakota sandstone is encountered at depths varying from about 500 feet near the western edge of the Red River Valley to 1,800 feet and over not far west of the James River and near the edge of the Missouri Plateau. The increasing depth of the formation is due both to the westward dip of the Dakota and the rise of the land surface in that direction. The depth of the sandstone at Enderlin is 640 feet; Valley City, about 800 feet; Oakes, 880 feet; Ellendale, 1,035 feet; and Jamestown, 1,450 feet. The deep well at Devils Lake, in the northeastern part of the state, struck the sandstone at 1,431 feet, while at Leeds, 30 miles northwest of Devils Lake, it lies at a depth of 2,110 feet. The Harvey well, near the center of the state, reached the Dakota at 2,235 feet, and a deep boring a few miles from Westhope, Bottineau County, entered the sandstone at about 2,100 feet. Though the well at Mandan reached a depth of 2,000 feet it failed to strike the Dakota, probably by several hundred feet.

As disclosed by the wells which penetrate it, the Dakota formation is a soft white or gray sandstone in beds 10 to 50 feet thick, separated by shale. In the regions where it occurs at the surface the sandstone has yielded an abundance of fossil leaves, the Dakota flora including no less than 450 species of trees and other plants.

GENERALIZED GEOLOGICAL SECTION OF NORTH DAKOTA

SYSTEM	SERIES	FORMATION NAME	COLUMNAR SECTION	THICKNESS IN FEET	CHARACTER OF ROCKS
QUATERNARY		LAKE SILT		0-30	Finely laminated sandy clay.
		Unconformity			
		GLACIAL DRIFT		0-400	Boulder clay, sand, gravel, & boulders.
		Unconformity			
TERTIARY	OLIGOCENE	WHITE RIVER FORMATION		40-400	Coarse sandstone containing pebbles, calcareous clay and fresh-water limestone.
		Unconformity			
	EOCENE	FORT UNION FORMATION		1000-1300	Yellow and ash-gray shale, sandstone, and clay, with numerous beds of lignite.
TERTIARY?		LANCE FORMATION		700-900	Cannonball marine member. Dark sandy shale, and shaly sandstone. Yellow sandstone, containing marine shells. 0-300 feet. Ludlow lignitic member. Light sandy shale, calcareous sandstone and lignite. 0-350 feet. Dark-colored shale, yellow sandstone and thin lignite beds. 400-525 feet.
		Unconformity			
CRETACEOUS	MONTANA GROUP	FOX HILLS FORMATION		150	Yellow sandstone, with numerous concretions and marine shells.
		PIERRE SHALE		1100	Blue shale containing marine shells.
	COLORADO GROUP	NIOBRARA FORMATION		400	Chalky limestone and calcareous shale.
		BENTON SHALE		500	Dark-colored marine shale.
		DAKOTA SANDSTONE		300	Sandstone containing many plant remains.

FIG. 1

The thickness of the sandstone varies widely at different points but is commonly 200 to 300 feet. In the asylum well at Jamestown it is 200 feet thick, and at Valley City 300 feet of Dakota sandstone were penetrated, while at Aberdeen, South Dakota, the same thickness was encountered. In the eastern part of the state the Dakota sandstone has a westward dip of about 8 feet per mile.

After the deposition of the Dakota sandstone, marine conditions were brought about through the submergence of a large part of North America. The Gulf of Mexico invaded the continent, and finally stretched north to the Arctic Ocean. All of North Dakota was covered by the waters of this great inland sea, which extended east as far as central Minnesota. In it were deposited the muds, clays, calcareous shales, and sands which form the Benton, Niobrara, Pierre, and Fox Hills formations.

Benton shale.—The oldest formation which outcrops anywhere in North Dakota is the Benton shale (Fig. 2). It is exposed only in the deep valley of the Pembina River, in the northeastern corner of the state, where the shale outcrops at intervals for a distance of 6 or 7 miles, and rises 150 feet above the river. It is also found in many of the deep wells in different parts of the state. The Benton is a dark gray, almost black, fissile shale, containing a considerable amount of carbonaceous material. Small ferruginous concretions are abundant, and pyrite and gypsum are found in small quantity. The shale weathers to a very plastic clay and has been used in the manufacture of brick. One very marked difference between the Benton and the overlying Niobrara is its low lime content, from 1 to 2 per cent, while the Niobrara contains from 30 to 80 per cent of lime carbonate and generally carries over 50 per cent.

The thickness of the Benton shale in North Dakota is not definitely known, since in wells it is seldom distinguished from the overlying Cretaceous shales. In the Morden, Manitoba, well the thickness of the Benton is given as 105 feet, and the well at Deloraine, just north of the Turtle Mountains in the same province, showed a thickness of 205 feet, but the well did not reach the underlying Dakota sandstone, so that this does not represent the entire thickness of the formation.[1] In North Dakota it probably ranges

[1] J. B. Tyrrell, *Trans. Royal Soc. Canada*, VIII, sec. 4 (1891), 93, 98.

GEOLOGICAL MAP OF NORTH DAKOTA
COMPILED BY A. G. LEONARD, STATE GEOLOGIST

GEOLOGICAL MAP OF NORTH DAKOTA
COMPILED BY
A.G. LEONARD, STATE GEOLOGIST
LEGEND
Quaternary
Lake Agassiz Silt
Tertiary
White River Formation
Fort Union Formation
Lance Formation (Tertiary?)
Cannonball Marine Member
Ludlow Lignite Member
Lower Member
Cretaceous
Fox Hills Sandstone
Pierre Shale
Niobrara Formation
Benton Shale
Scale
0 10 20 30 40 MILES

FIG. 2

from 200 to 600 feet or more. In northeastern South Dakota wells have encountered 400 to 480 feet of Benton.

While the Cretaceous formations have been largely removed by erosion from the Red River Valley, a dark-colored shale overlying a soft sandstone has been encountered in a number of wells in different parts of the valley, and it seems not improbable that this is the Benton shale. In that case this shale underlies the drift over a portion of the valley.

Niobrara formation.—Overlying the Benton, the upper member of the Colorado group is present in the wooded escarpment known as the Pembina Mountains, which border the Red River Valley on the west, in eastern Cavalier County. This escarpment extends far to the north in Canada, and the formation appears in the Tiger Hills, Riding and Duck mountains, and the Pasquia Hills. In North Dakota the Niobrara occupies a narrow belt extending 30 miles south of the international boundary, the outcrops being found along the Pembina, Tongue, north fork of Park River, and tributaries of these streams, which have cut deep valleys in the escarpment and exposed the Niobrara beneath the Pierre shale. A highly calcareous shale exposed in the valley of the Cheyenne River at Valley City is also probably to be referred to the Niobrara. It contains 45 per cent of carbonate of lime, and lies just below the black and white bands forming the base of the Pierre, as described on a later page.

The Niobrara is a light to dark gray, moderately hard calcareous shale. It contains numerous small white specks of lime which give it a finely mottled or speckled appearance, plainly seen on fresh fractures. Where the rock has been weathered it becomes almost white and has a chalky appearance; in fact, in many localities outside the state the formation is a nearly pure chalk. Its lime content, which is the most marked characteristic of the Niobrara, is due almost entirely to the presence of minute Foraminifera which are readily seen under the microscope. The most abundant forms are the two species so common in chalk, *Globigerina cretacea* and *Textularia globulosa*. The fact that these Foraminifera are mingled with clay is evidence that the sea in which they lived was not clear, but contained more or less fine sediment and the shells settled to

the bottom along with the clay to form the calcareous shale or chalky marl of this Cretaceous deposit.

The percentage of lime carbonate in the different layers varies widely, ranging from 30 per cent and less to 75 per cent. Many of the beds are suitable for making natural hydraulic cement and are used for this purpose, while certain layers have almost or quite the composition of a natural Portland cement rock.

Wherever the Niobrara formation is exposed in the Pembina Mountains it maintains a fairly uniform character throughout its thickness of 150 feet and more. By far the greater portion of the aggregate thickness is formed of a rather dark bluish-gray speckled rock, which commonly varies in lime carbonate content from 55 to 65 per cent in passing from one layer to another. Generally the more speckled the rock appears the higher it is in lime. Between these thicker beds high in lime carbonate are others much thinner, varying from a few inches to a foot in thickness, which are much lower in lime.

Where exposed in northeastern North Dakota the Niobrara strata have yielded a number of vertebrate and invertebrate fossils. Among the latter are *Inoceramus labiatus*, specimens of *Ostrea* and *Avicula*, besides the microscopic forms previously mentioned. The large diving bird, *Hesperornis*, several species of fishes, *Plesiosaurus*, and the vertebrae of a crocodile have also been found.

The maximum thickness of the Niobrara in the Pembina Mountains is 165 feet. At Morden, Manitoba, the formation is 160 feet, and farther north it averages from 150 to 200 feet, but seems to thicken toward the west, for the well at Deloraine, a few miles north of the Turtle Mountains, shows a thickness for the Niobrara of 545 feet. The formation probably has a thickness of at least 400 feet in southern and central North Dakota, since at Valley City the combined thickness of the Benton and Niobrara is about 900 feet. The artesian wells at this place reach the Dakota sandstone at a depth of approximately 800 feet below the bottom of the Cheyenne Valley, and the calcareous shale, which outcrops in the sides of the valley and is believed to be Niobrara, rises about 80 feet above the well curbs. The thickness of the beds between the top of the Dakota sandstone and the base of the Pierre is thus

about 900 feet at this point, and the Niobrara probably includes 300 to 400 feet of the section.

Pierre shale.—The Pierre shale occupies most of the eastern half of North Dakota west of the Red River Valley. It also outcrops along the valley of the Missouri River for a distance of over 20 miles north of the South Dakota line, and is brought to the surface in the southwestern corner of the state by the Cedar Creek anticline, which lies mostly in Montana. Throughout the large eastern area it is covered by glacial drift, except where the streams have cut through this mantle and exposed the shale beneath. The Pierre outcrops in many places along the James and Cheyenne rivers and is finely exposed along the South Branch of Park River and other tributaries of the Red River in the region of the Pembina Mountains. The escarpment of the Pembina Mountains is composed largely of this shale, which is well shown in the numerous ravines and gorges, while in places the underlying Niobrara is also seen. The base of the Pierre as found in this region is composed of black, jointed, carbonaceous shales which contain many thin layers of yellow or white non-plastic clay, which has much of the consistency of cheese. The black and yellow strata present a striking appearance and seem to be characteristic of the base of the Pierre over extensive areas. They appear at frequent intervals for a distance of 30 miles along the Pembina Mountain escarpment and extend at least 250 miles northwestward in Canada, where they have been noted in the Riding and Duck mountains. They are also found 130 miles south of the Pembina Mountains at Valley City. The yellow or white clay seams vary in thickness from 1 to 6 inches, and the interstratified black layers from 8 to 14 inches. The uniformity and extent of some of the yellow seams are remarkable because they have been traced continuously for a distance of 35 miles, and a single clay seam 2 inches thick for 25 miles.

The typical Pierre overlying these basal beds is a bluish-gray to dark gray jointed shale of remarkably uniform character, which often weathers into small flaky fragments. The rock commonly shows yellow spots or stains of iron oxide. Erosion has removed the upper part of the formation over most of the large eastern Pierre area, but the topmost beds, where exposed in the southwest

corner of the state, contain numerous calcareous concretions varying in size from a few inches to 6 and 8 feet in diameter. Many of these are rich in marine shells, including the following: *Scaphites nodosus* Owen vars. *brevis* and *plenus*, *Anisomyon patelliformis* M. and H., *Inoceramus cripsi* var. *barabina* Morton, *Avicula linguæformis* E. and S., *Ostrea pellucida* M. and H., *Chlamys nebrascensis* M. and H., *Yoldia evansi* M. and H., *Nucula cancellata* M. and H., *Lucina occidentalis* Morton, *Protocardia subquadrata* E. and S., *Callista deweyi* M. and H., and *Nautilus dekayi* Morton.[1]

Below the upper beds of the Pierre, fossils are found only sparingly, those which do occur being *Baculites ovatus* Say, *Scaphites nodosns* Owen, and *Inoceramus sagensis* Owen.

The position of the western boundary of the large Pierre area is known only approximately, since the region is heavily drift-covered and there are practically no outcrops. Not far west of the boundary as represented on the map (p. 7) Fort Union lignite beds are known to occur, so that the Pierre shale is believed to disappear beneath the overlying Fort Union about as shown. It will be noted that no areas of Fox Hills or Lance are represented on the map along most of the margin of the Pierre shale. These formations are not known to underlie the drift farther north than indicated on the map, and in the absence of information regarding their presence in the central and northern parts of the state they are not mapped in that region. If they are actually absent from that area it would of course mean an unconformity between the Pierre and the overlying Fort Union.

The Pierre is the thickest Cretaceous formation in North Dakota, reaching 1,000 to 1,100 feet or over. It is not likely that its entire thickness is represented throughout most of the large eastern area, since the formation had undergone great erosion before being covered by the glacial drift and hundreds of feet were doubtless removed in many places. The aggregate thickness of the Benton, Niobrara, and Pierre is considerably greater in North Dakota than in northeastern South Dakota. In the latter region the aggregate thickness of these formations ranges from 700 to 900 feet, but they become thicker to the north and northwest, where

[1] Identified by Dr. T. W. Stanton.

they reach from 1,300 to about 2,235 feet. At Jamestown they are 1,330 feet thick, at Devils Lake, 1,403 feet, Leeds, over 2,000 feet, and at Harvey they are not far from 2,235 feet thick. The deepest well in the state, at Max, 30 miles south of Minot, has a depth of about 2,400 feet, but it passed through drift, some Fort Union, and probably the Lance before entering the Cretaceous shales, and it did not reach the Dakota sandstone. The Deloraine well not far north of the international boundary went through 1,800 feet of shales, including some Fort Union strata, without reaching the Dakota.

Fox Hills sandstone.—This upper member of the Montana group is known to outcrop in three separate areas in North Dakota. The largest of these is along the Missouri River, where the formation is exposed for over 40 miles north of the South Dakota line and extending 5 to 10 miles on either side of the river. A narrow belt of Fox Hills sandstone surrounds the Pierre area in the southwestern corner of the state, and there is a small outcrop near the center of the state.[1]

The Fox Hills is particularly well shown along the Cannonball River for a distance of over 12 miles above its mouth, where the sandstone forms vertical cliffs rising from 80 to 90 feet above the river and is overlain by banded shale. The sandy portion of the formation is a yellow, rusty brown or gray, rather soft sandstone. Cross-bedding is very common, and the formation contains great numbers of large and small ferruginous sandstone concretions and indurated masses and layers, these also exhibiting cross-bedding. The concretions are apparently due to the segregation of the iron in certain portions of the rock, cementing the sand into firm, hard masses, considerably harder than the sandstone in which they are imbedded. These concretionary masses vary in size from an inch and less to 6 and 8 feet. Small, irregular, twisted or stemlike forms are abundant in places. Some portions of the rock are so completely filled with these rusty brown concretions that they constitute the main bulk of the formation, and the gray, loosely cemented sandstone forms a kind of matrix, in which the harder concretions are imbedded. In the process of weathering these

[1] Described by Dr. T. W. Stanton in a letter to the writer.

more resistant masses project beyond the softer rock, and at the base of slopes and scattered over the surface they are exceedingly abundant. Many of the concretions are spherical in shape and of good size, and it is these which have given the name to the Cannonball River, since they occur abundantly along that stream.

In the southwestern area in Bowman County the Fox Hills is composed of 60 feet of massive gray sandstone, which weathers to a yellow color, and below this is 25 feet of sandy clay formed of light and dark laminae.

Marine fossils are quite abundant in the Fox Hills sandstone, and the following are among those found in the Missouri River area and identified by Dr. T. W. Stanton: *Tancredia americana* M. and H., *Callista deweyi* M. and H., *Ostrea pellucida* M. and H., *Avicula linguiformis* E. and S., *Avicula nebrascana* E. and S., *Protocardia subquadrata* E. and S., *Tillina scitula* M. and H., *Mactra warrenana* M. and H., *Scaphitis cheyennensis* (Owen) and *Chemnitzia cerithiformis* M. and H.

The Fox Hills in North Dakota ranges in thickness from 85 to about 200 feet, with an average of about 150 feet.

CRETACEOUS OR TERTIARY SYSTEM

Lance formation.—As shown on the geologic map (p. 7) his formation occupies a considerable area on either side of the Missouri River in south-central North Dakota, and a smaller area in the extreme southwestern corner of the state. The beds are well exposed in the bluffs of the Missouri, particularly on the west side of the river 15 to 20 miles below Bismarck, and in many places along the Cannonball and Heart rivers. The bluffs and badlands of the Little Missouri in Slope and Bowman counties also afford many excellent outcrops.

As shown by Lloyd,[1] the Lance formation in south-central North Dakota consists of a lower portion of shale and sandstone beds of continental origin, and an upper member of sandstone and shale of marine origin which is known as the Cannonball marine member. Farther west in Slope and Bowman counties the upper member of

[1] E. R. Lloyd, "The Cannonball River Lignite Field, North Dakota," *U.S. Geol. Survey, Bull. No. 541*, 1914, p. 249.

the Lance is non-marine and lignite-bearing and has been named the Ludlow lignitic member.[1] The Cannonball marine and Ludlow lignitic members occupy similar stratigraphic positions and are believed to be contemporaneous in age.

The lower part of the Lance is best exposed in the badlands bordering the Little Missouri River in Bowman and Slope counties, where it is composed of shales alternating with soft gray or yellow sandstones, the beds having a notably dark and somber aspect. The prevailing colors are dark gray, but beds of brown carbonaceous shale are common and conspicuous. Much dark brown ferruginous material is present, occurring both in thin seams and concretions, the latter being most numerous at certain horizons, and fragments of this cover the slopes in many places. Another characteristic is the great number of sandstone concretions, some small and others 8 to 10 feet in diameter. Only occasional thin seams of lignite are found in the lower part of the Lance.

The Ludlow lignitic member in North Dakota is similar lithologically to the lower part of the Lance except that numerous beds of lignite are present. In western Slope County it contains at least 5 lignite beds which are from 4 to 30 feet in thickness.

The flora of both the lower part of the Lance and the Ludlow lignitic member is similar to that of the overlying Fort Union, the great majority of the species being common to both formations, according to Knowlton.[2] The Lance thus has a Fort Union flora. The characteristic vertebrate fossils of the Lance are the three-horned dinosaur *Triceratops*. *Trachodon* bones are also present in these beds.

The Cannonball marine member has been mapped only west of the Missouri River, and while, in the absence of outcrops, it is not represented on the geologic map as occurring east of the river, it seems not unlikely that it may be present beneath the drift, and that a portion of the area mapped as the lower member of the Lance is occupied by the Cannonball marine member. On account of

[1] E. R. Lloyd and C. J. Hares, "The Cannonball Marine Member of the Lance Formation of North and South Dakota and Its Bearing on the Lance-Laramie Problem," *Jour. Geol.*, XXIII (1915), 523–47.

[2] *Proc. Wash. Acad. Sci.*, XI (1909), 218–24.

the heavy covering of drift the eastern boundary of the area is probably only approximately correct.

Not only is the Cannonball marine member well exposed along the river from which it is named, but it is also well shown in many outcrops along the Heart River in the vicinity of Mandan and in the bluff of the Missouri near Bismarck. It is composed of dark gray to black shale, arenaceous in part, with a subordinate amount of gray and yellow sandstone. Some thin beds of limestone are also present.

After the deposition of the Fox Hills sandstones the Cretaceous sea withdrew from the region for a time and the beds constituting the lower part of the Lance were formed. These and the Ludlow lignitic member of the western area are of continental origin and were probably formed in part by rivers, though much of the formation may be of lacustrine origin. As the lakes were filled with sediment, they were converted into swamps in which trees and other vegetation grew and accumulated year after year to form the beds of lignite which are characteristic of the upper non-marine portion of the Lance. But while this Ludlow lignitic member was being deposited to the west the sea again entered the region, perhaps from the east, and in its waters were formed the Cannonball marine member, with its abundant fauna of marine shells, which Dr. Stanton characterizes as a modified Fox Hills fauna.[1] That this sea may have extended westward almost to the Montana line is suggested by the occurrence in the Little Missouri badlands of western Slope County of a bed containing *Ostrea glabra* and *Ostrea subtrigonalis*. Since these oysters are brackish-water forms the open sea was probably not far distant, and the shale bed containing them appears to be the westward extension of the Cannonball marine member. The zone in which the shells are found lies 120 feet below the top of the Ludlow lignitic member. Following the deposition of the Cannonball marine member the sea withdrew from the region never to return again.

The thickness of the Lance formation along the Little Missouri is about 820 feet, the upper 300 feet representing the Ludlow lignitic member. In the Cannonball River region the Lance is about 700 feet thick.

[1] E. R. Lloyd and C. J. Hares, *op. cit.*, p. 537.

The relation of the Lance formation to the underlying Fox Hills is of importance as bearing on the age of the former. In many localities in Wyoming, Montana, and South Dakota, where the contact has been observed, the Lance rests unconformably on the Fox Hills. On Little Beaver Creek in northwestern Bowman County the Fox Hills sandstone had undergone erosion before the deposition of the Lance beds, and although it has been questioned whether this erosion represents a long time interval, the relationship elsewhere suggests the probability that the unconformity here may represent a considerable interval.

Lying as it does on the border line between the Cretaceous and Tertiary, with its Fort Union (Tertiary) flora and its vertebrate fauna of Mesozoic types, the age of the Lance formation is still undetermined. Some would place it in the Tertiary while others would include it with the Cretaceous on account of its dinosaurs and other Mesozoic forms.

TERTIARY SYSTEM

Fort Union formation.—Overlying the Lance and resting in some places on the Cannonball marine member, in others on the Ludlow lignitic member, is the Fort Union formation. Deposition went on without interruption from the beginning of Lance time to the close of Fort Union time, during which over 1,800 feet of sediments accumulated, all of continental origin except those of the Cannonball marine member.

The Fort Union formation, which covers the greater part of western North Dakota, contains most of the lignite deposits of the state, the lignite beds of the Lance being relatively unimportant. Outcrops are abundant in the Little Missouri badlands, as well as along the Missouri and other streams of the region, and these extensive outcrops afford exceptional opportunity for the study of the formation. The Fort Union is remarkably uniform in color, composition, and general appearance over many thousands of square miles. It is composed of shales alternating with soft sandstone and contains numerous beds of lignite. The prevailing colors are light ash gray and yellow, but some layers are nearly white.

One of the most conspicuous features of the Fort Union is the vast quantity of baked and fused rock, or clinker, produced by the heat of the burning lignite beds. The overlying shales and sandstones have been burned to a red or pink color and in places completely fused to slaglike masses. This clinker caps many of the ridges and buttes of the region, having protected them from erosion by its superior hardness. The beds of clinker vary in thickness from 5 or 6 to 40 feet and over, the thicker masses probably having been produced by the burning of several lignite beds and the baking of the intervening shales, all now forming a single bed.

The Fort Union everywhere contains numerous beds of lignite. These vary in thickness from an inch and less to 35 feet, beds 6, 8, and 10 feet thick being common. Many of the lignite beds cover large areas. One with a thickness of from 5 to 16 feet has a known extent of 20 miles in one direction and 25 in another, thus covering an area of at least 500 square miles. Another is known from its outcrops to have an area of over 900 square miles, and its probable extent is from 1,000 to 1,500 square miles. This bed ranges in thickness from 9 to 15 feet and over. The lignite is found from top to bottom of the Fort Union, and since it is present also in the upper part of the Lance formation it has a vertical range of from 1,200 to 1,300 feet.

The Fort Union, which is Lowest Eocene, or Paleocene, in age, contains an abundant flora, about 300 species of plants having been described from this formation. It has a fauna comprising both fresh-water shells and vertebrates. Among the former are *Unio priscus* M. and H., *Viviparus trochiformis* M. and H., *Viviparus leai* M. and H., *Viviparus retusus* M. and H., *Campeloma multilineata* M. and H., *Campeloma producta* White, and *Corbula mactriformis* M. and H. Among the vertebrate remains are fishes, turtles, the aquatic reptile *Champsosaurus laramiensis*, and mammalian teeth.

A large part of the Fort Union formation has been removed by erosion and only in the higher buttes and divides of western North Dakota has the upper part been preserved. In Billings and Golden Valley counties it has a thickness of 1,000 feet, while farther north, in McKenzie County, the formation reaches 1,300 feet in thickness.

The shales and sandstones of the Fort Union appear to be very largely of lacustrine origin. The channel sandstones and the conglomerates which are present in places at the base of the formation were probably deposited by rivers, as were some of the shales and sandstones above, but the greater part of the sediments appears to have been laid down in lakes, many of them of large size and occupying parts of North Dakota, Montana, South Dakota, Wyoming, and a considerable area in Canada. This region is believed to have been a great flat plain occupied by numerous lakes, and over this plain large sluggish rivers took their meandering course. Thus deposits made on the flood plains of rivers, and wind deposits, are doubtless represented in the Fort Union, along with lacustrine deposits, which make up the bulk of the formation.

Various features characteristic of fluviatile deposits, such as local unconformities and filled channels, are, so far as known, not found in the Fort Union except at the base of the formation, and cross-bedding is of rare occurrence in the sandstones. Were the shales and sandstones of the Fort Union formed chiefly through deposition by rivers the foregoing features should be present, and the fact that except for a little cross-bedding they are not found above the base suggests that the deposits are lacustrine in large part.

The numerous lignite beds of the Fort Union are evidence that the region was occupied again and again by swamps, many covering hundreds and even thousands of square miles. These were probably formed by the partial filling of the lakes with sediment brought in by rivers, thus converting them repeatedly into swamps. The coal-forming vegetation growing in these swamps consisted, as determined by Thiessen,[1] very largely of coniferous trees, including varieties related to the Sequoia, cypress, juniper, and arbor vitae, together with some firs and spruces. The woody material of these trees, including trunks, stems, and branches, comprises roughly 75 to 85 per cent of the whole mass of the lignite. That the vegetation accumulated in some of these swamps for thousands and tens of thousands of years is indicated by the fact that several

[1] David White and Reinhardt Thiessen, "The Origin of Coal," *Bureau of Mines, Bull. No. 38*, 1913, p. 222.

of the lignite beds have a thickness of 20 feet and one of 35 feet. That the coal swamps recurred repeatedly in many parts of the region is proved by the presence in some vertical sections of as many as 15 or 20 lignite beds, the majority of them, it is true, of no great thickness. Among the lakes and swamps there grew many varieties of trees, including, according to Knowlton,[1] the poplar, oak, walnut, fig, elm, maple, birch, alder, dogwood, hickory, box elder, buckthorn, viburnum, witch-hazel, horse chestnut, and bittersweet. Interspersed with these were scattered conifers and ginkgos. Thus during Fort Union time North Dakota and adjoining areas were covered with dense forests. Osborn thus describes the region as it was at this period: "Vast stretches of subtropical and more hardy trees were interspersed with swamps where the vegetation was rank and accumulated rapidly enough to form great beds of lignite. Here were bogs in which bog iron was formed. Amid the glades of these forests there wandered swamp turtles, alligators, and large lizards of the characteristic genus *Champsosaurus*."[2]

White River formation.—The deposition of the Fort Union sediments was followed by a long erosion interval during which hundreds of feet of strata were removed. Erosion was going on during most of the Eocene period, and a well-marked unconformity therefore separates the Fort Union from the overlying White River formation of the Oligocene.

The White River beds occupy a number of small and widely scattered areas west of the Missouri River. It is necessary to exaggerate the size of these areas in order to represent them on the geologic map (p. 7). The formation is especially well exposed in White Butte, in Slope County, where it covers an area of 8 to 10 square miles, forming the highest portion of the divide at the headwaters of the north fork of the Cannonball River and Sand and Deep creeks. It is here composed of white clays at the bottom, on which rests a coarse sandstone filled in places with large pebbles; this is overlain by about 100 feet of calcareous clays, which in turn are overlain by more than 100 feet of fine-grained greenish sandstone. These deposits represent all three members of the White

[1] F. H. Knowlton, *U.S. Geol. Survey, Bull. No. 611*, 1915, p. 59.

[2] H. F. Osborn, *The Age of the Mammals*, p. 100.

River formation, the lower or Titanotherium beds, the middle or Oreodon beds, and the upper or Protoceras beds.

It is probably this area, in what was then Dakota Territory, which was visited by E. D. Cope in 1883, and from it he collected twenty species of vertebrates, including *Trionyx, Galecynus gregarious, Aceratherium, Elotherium ramosum, Oreodon, and Leptomeryx.*

The beds of the White Butte locality have been described in considerable detail by Earl Douglass,[1] and in the middle member, or Oreodon beds, he found the following vertebrate fossils: *Ictops, Ischyromys, Palaeolagus, Merycoidodon culbertsoni, Leptomeryx evansi, Mesohippus, Hyracodon, Gymnoptychus, Eumys,* and *Aceratherium.* Another White River area was discovered by Douglass about 30 miles northeast of White Butte, in western Stark County. All three members of the White River formation are here present and contain mammalian bones.

The 40 feet of calcareous clay and compact, siliceous, thin-bedded limestone occupying a few acres on top of Sentinel Butte, in Golden Valley County, is referred to the White River formation. Seventy miles east of White Butte, in Grant County, the White River formation occurs on the tops of three high buttes. The deposits are briefly described by E. R. Lloyd[2] as consisting of about 50 feet of calcareous sandstone overlying a marly limestone, both being referred to this formation "on faunal and lithologic evidence."

Far to the north of the above-mentioned areas, in the Killdeer Mountains of northwestern Dunn County, there are 400 feet of strata which are so wholly unlike the underlying Fort Union, on which they rest unconformably, that they have been referred to the White River formation. This area has recently been described by T. T. Quirke.[3] The deposits here consist of green or pink non-plastic clays, green friable calcareous sandstones, limestones, and chalklike arenaceous marl. The rocks are similar in character to those of the White River formation found elsewhere in the region, and they undoubtedly belong to that formation.

[1] *Annals of the Carnegie Museum,* V, Nos. 2 and 3 (1909), 281–88.

[2] E. R. Lloyd, "The Cannonball River Lignite Field, North Dakota," *U.S. Geol. Survey, Bull. No. 541,* 1914, p. 251.

[3] T. T. Quirke, "The Geology of the Killdeer Mountains, North Dakota," *Jour. Geol.,* XXVI (1918), 255–71.

About 25 miles north and east of the Killdeer Mountains, in eastern McKenzie County, many of the high buttes are capped with 200 feet of strata resembling those in the Killdeer Mountains. It is believed that the greenish sandstones and greenish clays of these buttes are likewise to be referred to the White River formation.

The strata in all these localities are clearly only remnants of much larger areas which have suffered extensive erosion and only relatively small patches of the White River formation have been left. It is not unlikely that several of those nearest together may formerly have been connected.

The beds of this formation are in part lake deposits and in part river deposits. Those of Sentinel Butte, the easternmost areas in Grant County, and most of the beds of the Killdeer Mountains are doubtless of lacustrine origin, while portions of the deposits of White Butte and the next area to the north are likewise lake deposits. The coarse pebbly sandstones and perhaps other strata were deposited by rivers.

While western North Dakota was an area of deposition in Lowest Eocene or Paleocene time and also during the early part of the Oligocene epoch, nevertheless during most of the Tertiary period the region was undergoing erosion. This resulted in the removal of many hundreds of feet of strata over most of the state, and in places the aggregate thickness of the Cretaceous and Tertiary deposits thus carried away by streams amounted to 1,000 feet and over. The outlier known as the Turtle Mountains, the Fort Union strata of which were once continuous with those of the Missouri Plateau, was during this time separated from the plateau by the denudation of the intervening area. The broad depression of the Red River Valley was cut to a depth of 800 to 900 feet in the Cretaceous and older rocks of eastern North Dakota and Minnesota by a large northward-flowing river. The topographic features of the region west of the Missouri River, including the rolling uplands, the high ridges and divides, the numerous buttes, the escarpments, and badlands, were all formed in large measure by erosion during the Tertiary period, continued, of course, in the Pleistocene.

Since the Cretaceous and Tertiary strata were deposited they have undergone but little deformation, though the region has several times been elevated, in the aggregate to the extent of some

2,000 to 3,000 feet. Only locally has there been warping or folding of the strata, as in the Cedar Creek anticline, which extends from near Glendive, Montana, southeast into southwestern North Dakota.[1] This anticline was probably formed about the close of Fort Union time and prior to the deposition of the White River beds.

QUATERNARY SYSTEM

Pleistocene deposits.—The Cretaceous and Tertiary formations are largely buried beneath a mantle of Pleistocene deposits left by the ice sheets which once covered the region. These deposits conceal the bed rock except where they have been cut through by streams, thus exposing to view the underlying formations. With the exception of the Lake Agassiz silt of the Red River Valley the Pleistocene deposits are not shown on the geologica lmap (p. 7). but they cover the entire state, except the southwest corner. The preglacial surface on which they rest had undergone great erosion during the Tertiary period, as already stated, and was therefore doubtless quite uneven and rough and cut by many stream valleys. These surficial deposits rest on the Archean granite and Paleozoic rocks in the Red River Valley; farther west they rest on the Pierre and other Cretaceous formations, and in western North Dakota they directly overlie the Tertiary strata. They overlie the earlier formations without regard to altitude, the surface on which they rest ranging in elevation from 450 to 2,500 feet above sea-level.

Glacial drift.—The only portion of the state which was not buried beneath the Pleistocene ice sheets, and hence did not receive a deposit of drift, is the southwest corner. The drift extends from 40 to 60 miles west and south of the Missouri River, though it is here represented largely by gravel and bowlders, since the till is thin and in scattered patches.

There are at least two, and probably three, drift sheets in North Dakota, namely, Late Wisconsin, Early Wisconsin, and an older drift, which may be referred to provisionally as the Kansan, though it may prove to be younger. The Late Wisconsin drift covers

[1] A. G. Leonard, *U.S. Geol. Survey, Bull. No. 285*, 1906, p. 317; *No. 316*, 1907, pp. 195, 203; W. R. Calvert, *U.S. Geol. Survey, Bull. No. 471*, 1912, p. 201.

considerably over one-half the state, including the eastern and northwestern portions, and its western border is marked by the wide, massive Altamont moraine, which in places has a width of 20 miles and over. Outside of the Altamont moraine there is in northwestern North Dakota and perhaps elsewhere in the state a drift which is little older than that within the moraine, and is itself marked by occasional morainic patches. This young drift, which in Williams County extends 20 miles or more south of the Altamont moraine, is probably Early Wisconsin. Beyond the Early Wisconsin till and appearing at the surface for the most part west and south of the Missouri River, is a distinctly older drift whose age is not yet definitely determined, but which may be Kansan. This pre-Wisconsin drift has been described elsewhere[1] and need not be discussed more fully here. It forms well-developed moraines in northeastern Morton and northern McKenzie counties.

In marked contrast to the older drift the Wisconsin has suffered very little erosion, its surface is poorly drained, is characterized by almost countless lakes, ponds, swamps, and marshes, and by many rough, hilly, morainic belts. Twelve of these moraines, including the remarkably wide and massive Altamont moraine, have been mapped in eastern North Dakota[2] and adjoining regions.

The drift varies in thickness from a few feet to 300 and even 400 feet, though the latter thickness is probably exceptional. In the Red River Valley the till is commonly from 200 to 300 feet thick, and in other parts of the state covered by Wisconsin drift the thickness appears to be somewhat less, ranging usually from 150 to 250 feet. The pre-Wisconsin drift is much thinner, the maximum thickness so far noted being 100 feet. West of the Missouri River it is seldom as much as 8 or 10 feet and generally not over 2 or 3 feet or less.

Lake Agassiz silt.—In the Red River Valley the glacial drift is in most places covered by a fine silt which was deposited in Lake Agassiz toward the close of the Pleistocene. Associated with this

[1] A. G. Leonard, "The Pre-Wisconsin Drift of North Dakota," *Jour. Geol.*, XXIV (1916), 521–32.

[2] Warren Upham, "Glacial Lake Agassiz," *U.S. Geol. Survey, Mono. No. 25*, Plate XVII.

are alluvial deposits spread over the surface by the Red River and its tributaries. This fine, thinly laminated silt commonly has a thickness of 30 to 50 feet, though in places it is considerably less.

Where rivers entered the lake the sediment carried by them accumulated to form delta deposits. Three such deltas are found in North Dakota, the largest, formed by the Cheyenne River, covering an area of about 800 square miles. The sand of this delta has been heaped by the wind into dunes, and a large tract of the delta is covered by these sand hills.

Recent deposits: alluvium.—Alluvium is found along practically all the streams of the state, being deposited by the rivers over their valley bottoms in time of flood, and in some of the larger valleys it has accumulated to a considerable depth. It is composed of sand, clay, and gravel, the upper 2 or 3 feet being commonly clay. The belt of alluvium along the Missouri River averages 2 to 3 miles in width. As shown by borings, the silt deposited by this river reaches in places a thickness of nearly 100 feet. Some of it may have been deposited during the Pleistocene, but much of this alluvium of the Missouri and other rivers belongs to the Recent epoch.

Quaternary history.—In conclusion the course of events during the Quaternary period may be briefly described. At the close of the Tertiary the warmth of a temperate climate gave way to the rigors of an arctic cold. North Dakota was several times invaded by an ice sheet and many of the surface features as we find them today are the result of these invasions, particularly of the most recent one. The ice of the earlier invasion crossed the broad and deep valley of the Missouri and extended from 40 to 60 miles beyond that river. The deposits of this older glacier are in most places thin and appear to have undergone much erosion. This drift west of the Missouri may never have been very thick, except locally, where it forms moraines, and much of the finer material of the till has been swept away by the streams, leaving behind the gravel and bowlders.

This ice invasion produced important changes in the preglacial drainage of the region. The Missouri Valley and the lower valleys of the Yellowstone and Little Missouri rivers were blocked with

ice, so that all these streams were forced to seek new channels. Lakes were formed in the valleys of the Yellowstone and Little Missouri rivers, the water rising until it overflowed at its lowest point the divide between the latter and the Knife River. The combined waters of the three rivers flowed east and southeast to the mouth of the Cannonball, where they entered the Missouri Valley. The length of this Pleistocene valley from the head of the Knife to the mouth of the Cannonball is 155 miles. Upon the withdrawal of the ice sheet the Missouri and Yellowstone rivers returned to their former valleys, but the lower valley of the Little Missouri was permanently abandoned and that river took an easterly course from the point where its preglacial course was blocked by the front of the ice sheet.

After the first invasion the climate grew warmer and the glacier retreated northward, so that conditions were probably favorable for the return of animal and plant life. Upon the recurrence of the cold climate the ice sheet again advanced over the region and probably reached about to the Missouri River. Evidence that this second advance crossed the latter stream is lacking, and it is known to have stopped far short of the limits reached by the first invasion. Then after a relatively short interglacial interval, during which the glacier withdrew from the region, there was a third invasion of the ice sheet, coming as before from the center west of Hudson Bay. The limit reached by this Late Wisconsin ice sheet is marked by the Altamont moraine. This remarkably well-developed moraine forms a very rough belt of massive hills and ridges which extends without interruption for hundreds of miles. In places it is fully 20 miles wide and throughout much of its extent in North Dakota its width probably averages 12 to 15 miles. While forming the moraine the ice front doubtless fluctuated back and forth across the belt for a long period.

During its recession the ice sheet halted again and again and thus built a series of moraines. Some of these halts were brief and the resulting moraines poorly defined; others were of much longer duration, as shown by the great amount of material deposited and the large size of the hills and ridges.

Science & Industry
Department

Lake Agassiz: The early history of Lake Agassiz, according to Upham,[1] was intimately connected with the recession of the ice front, since when the glacier had retreated across the divide between the Minnesota and Red rivers the lake was formed by the ponding of the water at the south end of the Red River Valley. According to this view, Lake Agassiz began as a small body of water and expanded northward as the ice melted until its maximum was attained, its area at that time being about 110,000 square miles.

Recently W. A. Johnson, of the Canadian Geological Survey, has attributed a different life-history to Lake Agassiz.[2] He believes with Tyrrell that after the retreat of the Keewatin glacier northward into Manitoba there was comparatively free drainage in that direction, so that an earlier glacial marginal lake associated with a lobe of the Keewatin glacier was largely or wholly drained. Lake Agassiz proper did not come into existence until a later advance of the ice from the northeast was met by a slight advance of the Keewatin glacier, which resulted in the ponding of the northward drainage and the initial stage of the lake. The waters gradually rose and extended southward, filling the Red River Valley and overflowing to the south.

It will be noted that these two views differ radically, one holding that the lake began at the upper or south end of the valley and expanded northward with the retreat of the ice margin; the other, that the lake originated well to the north in Manitoba after much of the Red River Valley was already free of ice, and had first a rising stage as it increased in size and extended southward over the valley floor. But in either case Lake Agassiz owed its existence to the presence of the ice barrier to the north and northeast, higher land holding in its waters on the other sides of the basin.

This Pleistocene lake left its mark on the region in the form of beaches, deltas, and lacustrine silts. The gradual retreat of the ice barrier which held the lake in place afforded outlets at different levels, and at many of these stages the water remained long enough to form more or less distinct beach lines. A series of beach ridges

[1] Warren Upham, "Glacial Lake Agassiz," *U.S. Geol. Survey, Mono. No. 25.*

[2] W. A. Johnson, "The Genesis of Lake Agassiz," *Jour. Geol.*, XXIV (1916), 625–38.

were thus formed, the best developed of which commonly rise 10 to 20 feet above the adjoining surface on the side toward the former lake. They are composed of interstratified gravel and sand, and vary in width from 10 to 30 rods.

These beaches afford evidence of the elevation of the land to the north, since they are no longer horizontal, nor are they parallel, but show a divergence among themselves. All have a gradual ascent toward the north or northeast; the upper or Hermon beach, for example, rises 175 feet between Lake Traverse, at the south end of Lake Agassiz, and the international boundary. As these shore lines also show a divergence among themselves it is evident that this upward movement of the earth's crust began while Lake Agassiz was in existence and was probably largely completed before the lake was finally drained.

Sand and gravel deltas, so extensive as to constitute notable topographic features, were formed by the streams that flowed into Lake Agassiz while it stood at its highest stage. Those in North Dakota were formed by the Cheyenne, Pembina, and a Pleistocene river no longer in existence. Much of the finer sediment contributed to the lake by the inflowing streams was carried by the waves and currents and spread over the bottom of the lake as a fine silt. It is this fine loam, mingled with decayed vegetation, which forms the rich black soil of the Red River Valley, one of the great wheat regions of the world.

So recent is it geologically since the last ice sheet withdrew from North Dakota, and since Lake Agassiz was drained, that the drift surface and lake bed have been but slightly affected by erosion, and are still much as they were left at the close of the glacial period.

PEGMATITE, SILEXITE, AND APLITE OF NORTHERN NEW YORK[1]

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INTRODUCTION

During twelve seasons of field work in the Adirondack Mountain region of New York, the writer has made many hundreds of observations on bodies of pegmatite, quartz (silexite), and aplite. Certain of the phenomena long proved to be very puzzling, and more recently it has become evident that some generally accepted interpretations of such phenomena are not satisfactory when applied to many of the occurrences in the Adirondack region. While engaged in the detailed geologic mapping of the Lyon Mountain quadrangle, the writer was soon impressed by the exceptional opportunity for a careful study of the pegmatite, quartz (silexite), and aplite bodies which are there so wonderfully exhibited in countless numbers. Many detailed notes were taken and sketches were made. The North Creek quadrangle, surveyed by the writer some years ago,[2] was also revisited for the purpose of making further observations on certain pegmatites there so well exhibited. In this paper the discussions deal almost entirely with the Lyon Mountain and North Creek quadrangles.

PEGMATITE, SILEXITE, AND APLITE IN THE GRANITES OF THE LYON MOUNTAIN QUADRANGLE

The granites.—Several varieties of granite and granitic syenite constitute the main bulk of the rocks of this district. Among these the variety of chief interest in the present discussion is a fine to medium-grained, usually pink rock varying from a true granite through granitic syenite to quartz syenite or even quartz diorite. In the more typical specimens of granite dark minerals,

[1] Published by permission of the state geologist of New York.

[2] W. J. Miller, *N.Y. State Mus., Bull. 170.*

except magnetite, are either almost wholly absent, or they make up less than 5 per cent of the rock. Thin sections of the typical granites contain microperthite, 45 to 70 per cent; quartz, 25 to 35 per cent; oligoclase, 5 to 25 per cent; usually microcline, 5 to 15 per cent; magnetite, ½ to 2 per cent; and usually less than 2 per cent of one or more of the following: titanite, hornblende or pyroxene, biotite, zircon, apatite, and hematite (stains). Locally, probably owing to incorporation of material from older basic rocks, dark minerals, including hornblende, monoclinic pyroxene, and biotite, are fairly conspicuous. A magmatic flow-structure foliation is generally more or less well developed in the granite, but some portions of the rock which are almost free from dark minerals exhibit practically no foliation to the naked eye.

The writer proposes to call the rock just described the "Lyon Mountain granite" because of the excellent exposures in and near the village of Lyon Mountain. This rock is also extensively developed on Johnson Mountain, Duncan Mountain, and in the valley of the Saranac River. The Lyon Mountain granite is perhaps the most conspicuous member of Cushing's "Saranac formation."[1] This Lyon Mountain granite contains a truly wonderful display of pegmatite and quartz (silexite) in the form of dikes, segregation masses, and inclusions. In many places the granite is very highly pegmatized. All the numerous magnetic iron-ore deposits, including those of the Lyon Mountain mines, occur in this granite. The structure and origin of these deposits are discussed by the writer in another paper.[2]

There is considerable field evidence to show that the Lyon Mountain granite grades into and is only a facies of a coarse-grained rock which the writer proposes to name the "Hawkeye granite" because of its excellent outcrops just east of Hawkeye post-office. In thin section the rock from the type locality shows microcline, microperthite, and quartz in about equal amounts; 8 to 10 per cent of oligoclase to albite; and small quantities of biotite, apatite, zircon, magnetite, chlorite, and secondary calcite.

[1] H. P. Cushing, *N.Y. State Mus., Bull. 95* (1905), pp. 299–303.

[2] W. J. Miller, *N.Y. State Mus. Bull.*, on the geology of the Lyon Mountain quadrangle soon to appear.

At the summit of Lyon Mountain the rock contains 2 or 3 per cent each of hornblende, diallage, and bronzite. The feldspar and quartz crystals are usually from one-fourth of an inch to an inch long. Where fresh the rock is greenish gray. It weathers to a light brown. A gneissoid structure is generally more or less well developed, though considerable bodies of the rock may show it scarcely at all. The Hawkeye granite is extensively developed in Silver Lake Mountain and in the southeastern half of the great mass of Lyon Mountain.

More locally the Lyon Mountain granite grades through granitic syenite into quartz syenite and even into quartz diorite.

Silexite in the granites.—The term "silexite" is elsewhere proposed[1] by the writer for any body of pure or nearly pure silica of igneous or aqueo-igneous origin which occurs as a dike, segregation mass, or inclusion within or without its parent rock. So-called "quartz dikes" are included under "silexite."

Hundreds of silexite masses were observed in the granites of the Lyon Mountain quadrangle. They are most abundant by far in the Lyon Mountain granite. The evidence that they are not true veins is decisive. None of them ever shows crustification, and many of them grade into true pegmatite. Thus at the summit of Duncan Mountain and also just south of the southern summit of Alder Brook Mountains, where both pegmatite and silexite are grandly exhibited in the large, bare ledges of Lyon Mountain granite, one may observe every possible gradation from typical, moderately coarse-grained pegmatite, consisting mostly of pink potash feldspar and some quartz, to about equal amounts of feldspar and quartz, to mostly quartz, with some scattering crystals of feldspar, and to practically pure silica (silexite). Most of the silexite contains 1 or 2 per cent of feldspar in the form of small crystalline masses with rather blurred contacts against the silica. All the facies just mentioned occur on Duncan Mountain, not only in the form of dikes more or less parallel to the foliation of the granite, but also often as irregular bunches or lenses crudely parallel to the foliation, the original masses in the latter cases apparently having been broken up, pulled apart, and the pieces

[1] W. J. Miller, *Science*, in a number soon to be issued.

more or less shifted after they were developed, by movements in the granite magma, which still possessed a considerable degree of fluidity. Such breaking up and shifting of pegmatite and silexite masses appear to have been most notably true of the silexite. Many of the later pegmatite dikes (below described) exhibit no such phenomena. We are led to conclude, therefore, not only that many masses of practically pure silica (silexite) separated from the granite magma well before many of the ordinary pegmatites, but also that the separation of the silica took place well before the complete solidification of the granite magma. Accordingly those masses of silexite which developed early (probably as segregation masses) and were broken up and more or less shifted in the magma are to be regarded as inclusions in the granite.

The following sketches (Figs. 1, 2, 3) of portions of the ledges at the summit of Duncan Mountain will suffice to make clear the foregoing conclusions. Figure 1 shows seven fragments of silexite. Evidently they represent portions of one or more masses which were broken up and strung out in the magmatic current. The wrapping of the magmatic flow-structure about the fragments is very evident. Contacts of the silexite against the granite are sharp. That these fragments are true inclusions of silexite which must have developed (probably by segregation) well before the final consolidation of the granite magma is strongly supported by the undoubted inclusions of both Grenville strata and an old gabbro which, in the Lyon Mountain district, have been observed to bear exactly similar relations to the granite (see Fig. 5). Unlike the Grenville and gabbro inclusions, however, the fragments of silexite are not distinctly older than the granite. They are early facies of the pegmatitic masses which developed during the intrusion of the granite and probably after the magma had come nearly to rest. Thus other nearby ledges of granite at the top of Duncan Mountain show distinct inclusions of silica which contain varying amounts of feldspar, though seldom more than 15 or 20 per cent. Usually with increased feldspar content the contacts against the granite are less sharp. Also in many cases silica, usually with a small content of feldspar, still exists in rather distinct dikelike form with only fairly sharp contacts against the granite. Again,

in many cases, practically pure silexite and ordinary pegmatite, the one grading into the other, occur in the same inclusion or dike. Just south of the southern summit of Alder Brook Mountains the large bare ledges contain many pegmatite and silexite masses which exhibit the features just described, the pegmatite and silexite there often grading into each other. Some of these cut the granite very irregularly in true dike form without very sharp contacts. Phenomena like those above described have been observed in many parts of the Lyon Mountain quadrangle.

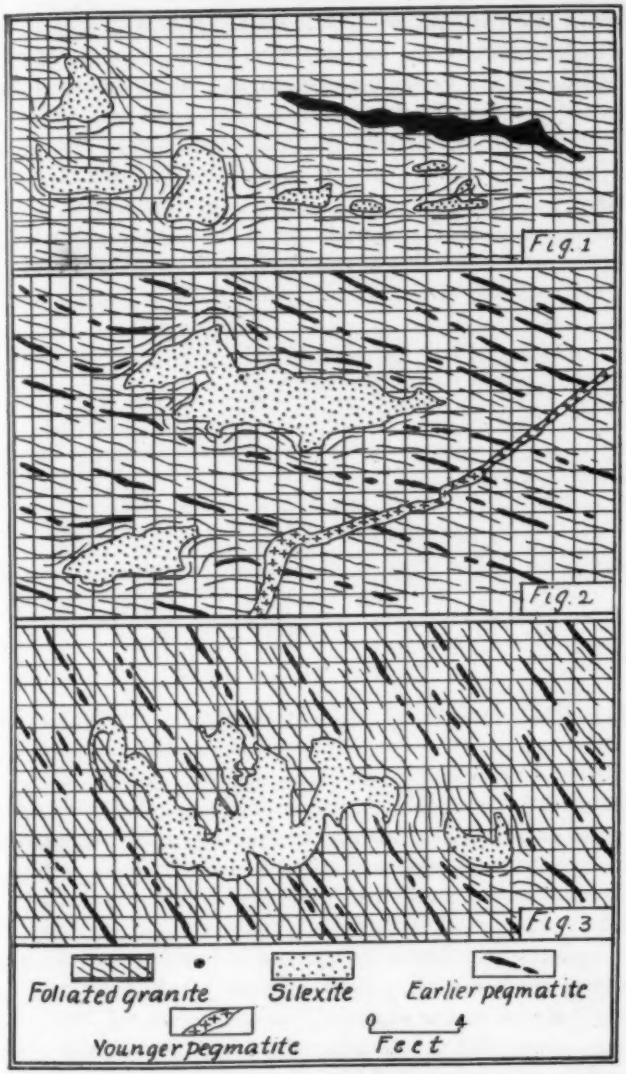
Figure 2 shows two larger masses of nearly pure silica (silexite) with their long axes parallel to the fluxion structure of the inclosing granite, with very distinct magmatic flow-structure foliation curved about them, and with sharp contacts against the granite.

A more exceptional case is shown by Fig. 3. The larger mass of silexite is exceedingly irregular in shape, and it locally contains considerable feldspar. Both inclusions seem to lie almost at right angles to the foliation of the granite, though it is quite possible that this ground-plan sketch does not actually represent the position of the whole original larger mass of silexite from which the inclusions were derived in the granite. Fluxion structure is locally distinctly curved on one side of the smaller fragment of silexite, and also between it and the larger fragment.

Figure 4 shows a very interesting silexite dike unusually thick at one end and with five clearly defined dikelike branches cutting the granite at the other end. The silexite contains not over 10 per cent of feldspar scattered through it in tiny masses. Contacts against the granite are only fairly sharp, and the foliation of the granite nowhere curves around the silexite. This is quite certainly a true dike of silexite, and it was formed later than the silexite of Figs. 1, 2, and 3, so it was not pulled apart by the granite magma which had already nearly or quite consolidated.

A small lens of silexite occurs as a distinct inclusion with sharp contacts in one of the later pegmatites (see below) on the low ridge one mile east-northeast of Goldsmith.

A mass of nearly pure silica (silexite) which demonstrably formed well before the solidification of the medium-grained granite which contains it occurs on the ridge one mile northeast of the



FIGS. 1, 2, and 3.—Sketches of portions of the ledges at the summit of Duncan Mountain in the Lyon Mountain quadrangle showing the relations of silexite and pegmatite to the foliated granite.

mouth of Two Brooks near Goldsmith. A lens of silexite was there pulled apart in the magma, some of which flowed into the intervening space. Contacts are sharp, and highly foliated granite occurs only close to the silexite.

Some interesting masses of silexite of relatively late origin occur in slightly foliated quartz syenite on the hill half a mile north of Mud Pond near Riverview. South of the summit of this hill several dikes of silexite contain very little feldspar, and they lie parallel to the foliation of the syenite, without sharp contacts. About 40 rods east of the summit of the hill a pegmatite dike 10

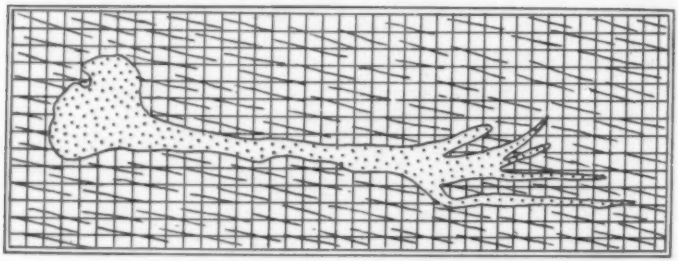


FIG. 4.—A mass of silexite 28 feet long with branching dikes in the granite on the ridge one and two-thirds miles north-northeast of Union Falls in the Lyon Mountain quadrangle.

inches wide and 15 feet long grades into the quartz syenite on either side and lies parallel to the foliation. The middle of the dike or segregation mass is nearly pure silica (silexite) which grades into the pegmatite. Near by a coarse-grained pegmatite dike several feet wide cuts obliquely across the foliation, this dike therefore belonging with the latest pegmatites below described.

Figure 5 represents a small portion of a belt of granite 25 to 30 feet wide and 100 feet long which contains many angular inclusions of silexite and Grenville quartzite and schist. All the inclusions have sharp contacts, and they mostly have their long axes roughly parallel to the magmatic flow-structure foliation which tends to curve about them. Masses of nearly pure silexite of very early origin were here pulled to pieces, and the pieces were moved in the still fluid granite.

Some fine examples of crudely lens-shaped masses of practically pure silica (silexite) have been observed by the writer in the Blue Mountain quadrangle in syenite, granite, and mixed gneisses apparently always parallel to the foliation of the inclosing rock. In one case a small dike of pegmatite sharply cuts a long, narrow lens of silexite.

Earlier pegmatites.—A great many masses of true pegmatite of early origin lie in the Lyon Mountain granite parallel to its

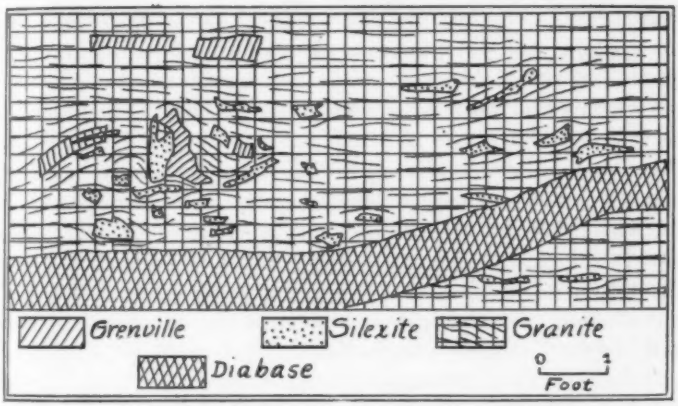


FIG. 5.—Angular inclusions of both silexite and Grenville quartzite in foliated granite at the top of the hill one-third of a mile south-southwest of Barnes Pond in the Lyon Mountain quadrangle.

foliation. The mineral content of these early pegmatites is remarkably simple, by far the greater number of them consisting very largely of quartz and potash feldspar (mostly microcline), some microperthite and oligoclase, and a little biotite. Some pegmatites, probably to be classed with the early ones, though not with the earliest, carry more or less magnetite, hornblende, or pyroxene, but these minerals appear to have been largely or wholly derived from the old dark gneisses and gabbro which were invaded by the granite. Minerals so common to pegmatites in general, such as tourmaline, garnet, muscovite, beryl, apatite, and others, must be exceedingly rare if they occur at all. The only mineralizer,

therefore, which could have been present in very appreciable quantity during the crystallization of these pegmatites was water. These pegmatites rarely if ever show graphic intergrowths.

In many localities from 10 to 50 per cent of the body of the granite consists of the earlier pegmatite either in the form of narrow parallel bands from a few feet to many feet long, causing the rock to look like a coarse-banded gneiss, or as rather distinct lenses up to several feet long; or in the form of "eyes" or very short, thick, more or less rounded or elliptical lenses usually not more than a few inches long and from one-half to two or three inches thick. The long, narrow bands almost invariably grade into the granite on either side, while the lenses and eyes generally show moderately sharp contacts against the granite. The mode of occurrence of such eyes of pegmatite is fairly well illustrated by Figs. 2 and 3, the granite containing the eyes, usually exhibiting rather wavy flow-structure foliation about them. From the field relations it is quite certain that the eyes and short, rounded lenses represent long lenses or layers of pegmatite which formed before the final consolidation of the inclosing granite, and which were pulled apart and strung out parallel to the magmatic currents which were deflected around them. Their mode of occurrence and lack of sharp contacts strongly suggest that they formed during a late stage of magma consolidation, and that they are not so old as the oldest silexite masses, which are now represented as sharply defined inclusions.

M. E. Wilson,[1] in a description of the gneisses of the Laurentian highlands, notes apparently similar lenses of pegmatite and says that a "lenticular character is particularly evident in the case of the pegmatite which commonly occurs in a succession of lenses around which the foliation of the surrounding gneiss bends."

Those pegmatites which occur as long, narrow, irregular bands or strips parallel to the granite foliation, and which grade into the granite, no doubt represent the final or nearly final solidification of those portions of the granite in which they occur, and hence they are practically *in situ* and grade into the granite. Figure 1 shows a single lens of such pegmatite.

[1] M. E. Wilson, *Amer. Jour. Sci.*, XXXVI (1913), 115.

A typical example bringing out the relation of the earlier to the later pegmatites occurs in a big ledge on the little hill just south of the mouth of Two Brooks near Goldsmith. Much of the granite contains streaks, lenses, and eyes, usually less than an inch wide and not over two feet long, of not very coarse pegmatite parallel to the foliation. This pegmatite makes up a very considerable percentage of the rock mass, with contacts varying from fairly sharp to not sharp. Cutting this combination of granite and pegmatite are several prominent later pegmatite dikes, six to eight feet wide and forty or fifty feet long, carrying equal amounts of quartz and feldspar and 10 per cent of biotite. These moderately coarse-grained later pegmatite dikes lie only partly roughly parallel to the granite foliation. This ledge calls to mind an exposure observed by the writer in the Blue Mountain quadrangle,[1] where lenses and eyes of pegmatite parallel to the foliation of a mixed gneiss are sharply cut across by a pegmatite dike of distinctly later origin.

On a little ridge one mile east-northeast of Goldsmith an outcrop shows two bands or long lenses of pegmatite parallel to the foliation of the granite and without very sharp contacts. The upper lens consists of two-thirds quartz and one-third feldspar, and it is very uniform. The lower lens is notably variable, with the different portions not sharply separated. Nearly pure silica (silexite) and typical pegmatite here developed side by side, while the inclosing granite was still somewhat fluid, as shown by the flow-structure along the lower side of the lens.

Near the road two miles east-southeast of Goldsmith a pegmatite dike, or rather a segregation mass, one foot wide and twelve feet long, which lies parallel to the foliation of the inclosing granite and grades perfectly into it, shades off into a zone of nearly pure silica (silexite) four to five inches wide toward its middle. Both the pegmatite and the silexite here developed side by side by segregation during a late stage in the solidification of the granite magma, and both pegmatite and silexite now occupy practically the place where they solidified.

A more exceptional mode of occurrence of the older pegmatites is illustrated in a ledge by an old road one mile northwest of the

[1] W. J. Miller, *N.Y. State Mus., Bull. 192* (1916), pl. 10.

mouth of Alder Brook. One mass of pegmatite a few feet wide perfectly exposed for twenty feet contains orthoclase crystals up to three or four inches long, and its boundaries against the granite are sharp. A very evident magmatic flow-structure follows the details of the very irregular boundary on either side within six inches of the pegmatite, but one or two feet out the foliation is practically straight. Evidently this typical pegmatite developed unusually early, probably by segregation, perhaps as early as some of the first-formed silexite, that is to say, when the granite magma still possessed a considerable degree of fluidity.

Later pegmatites.—As regards their mode of occurrence these later pegmatites are in most respects quite ordinary. They cut across the granite foliation at all sorts of angles, and hence they must have developed after complete, or at least almost complete, solidification of the granite which contains them. They are true dikes, generally coarser grained and usually larger than the older pegmatite masses above described. Many of them are from one to ten feet wide and from ten to fifty feet or more long. They rarely if ever exhibit graphic intergrowths. Contacts against the granite range from very sharp to moderately sharp, those with very sharp boundaries probably having developed in the solid, relatively cooler granite, while those with less sharp boundaries probably were intruded into essentially solid but relatively hot granite. Most of these dikes consist largely or wholly of pink or white potash feldspar and quartz; some contain hornblende or pyroxene, or both; some contain little or no quartz; some are almost pure quartz (silexite); a few contain scapolite, and many contain magnetite in amounts ranging from 1 to 40 or 50 per cent. With few exceptions these later pegmatites, like the earlier ones, do not contain any other minerals as well known in pegmatites in general. As pointed out below, the hornblende, pyroxene, and magnetite were almost certainly absorbed by the pegmatites from the old, invaded dark gneisses and gabbro. Apatite in small amount and many specks of titanite occur in some of the pegmatized zones of the granite in the main workings of the iron mine at Lyon Mountain village, and in somewhat greater amounts in the older workings to the east. Throughout the Lyon Mountain

A B C

FIG. 6.—A: Part of ledge one and one-fourth miles north of Disco in the Lyon Mountain quadrangle showing hornblende gneiss (probably meta-gabbro) more or less intimately injected with Lyon Mountain granite, the resulting mixed rock being cut by pegmatite and silexite. Silexite is well shown toward the middle of the picture and pegmatite just below the middle, the latter sending dikes across a large lens of the dark gneiss. Owing to pegmatization, much of the hornblende of the dark gneiss has been changed to pyroxene. The folding toward the top was caused by magmatic movement. Width of exposure about 15 feet.

B: Part of a ledge one mile east of Goldsmith in the Lyon Mountain quadrangle. The finer-grained portion is Grenville biotitic and quartzitic gneiss intimately injected with Lyon Mountain granite. The nearly white lenses and narrow strips are pegmatite and silexite developed during an early stage of the magma consolidation, and the broad band is pegmatite which formed late in the process of the magma solidification. Width of exposure about 15 feet.

C: Near view of part of the mass of pegmatite on the western side of the gabbro stock on the hill one mile south-southeast of the Glen in the North Creek quadrangle (see Fig. 8). Lower half is quartz and black tourmaline graphically intergrown, and upper half is mostly silexite. Width of exposure about 2 feet.

quadrangle, however, even these minerals are very rare or absent. Aside from water vapor, then, these later pegmatites must have been mostly relatively free from mineralizers.

Figure 2 shows one of the later pegmatites with fairly sharp contacts cutting across a ledge of granite which contains inclusions of silexite and eyes or inclusions of older pegmatite.

Near the top of the hill two miles east of Goldsmith a distinctly later pegmatite dike not only cuts across the foliation of the granite but also sharply cuts earlier-formed lenslike masses of both pegmatite and silexite.

Just south of the southern summit of Alder Brook Mountains several dikes of ordinary pink pegmatite grading into practically pure silexite cut the granite in all directions without very sharp contacts.

A fine ledge clearly exhibiting the relations of earlier pegmatite and silexite to later pegmatite occurs on the little hill one-fourth of a mile northwest of the mouth of the eastern of the Two Brooks near Goldsmith. Thin-bedded Grenville quartzite and gneiss are mostly highly injected with medium-grained granite, pegmatite, and silexite. This combination of rocks is locally much contorted, owing to magmatic movements, and the pegmatite and silexite, especially the latter, are much broken up and kneaded into the mass, thus proving that this pegmatite and silexite originated before the solidification of the granite magma. Ordinary pegmatites cut across this ledge of mixed rocks in true dikelike form at various angles, and they are not broken up, thus clearly indicating their distinctly later origin, that is, after the solidification, or at least almost complete solidification, of the granite magma.

Before leaving the consideration of the later pegmatites, the occurrence of magnetite, hornblende, and pyroxene in many of them should be briefly discussed. One or more of these minerals may be observed in the later pegmatites of the Lyon Mountain quadrangle in many places, but almost invariably only where the pegmatites are known to be directly associated with an older hornblende gneiss or gabbro, though not all the pegmatites thus associated contain one or more of the minerals mentioned. The

field evidence strongly points to a derivation of these minerals from the older basic rocks by the pegmatites during their intrusion. It is significant that more or less magnetite occurs in later pegmatites at every one of the dozen or more localities from which magnetic iron ore has been mined in the Lyon Mountain quadrangle and also at many other places. A few of the more typical field occurrences will now be briefly described.

In the old mine at Russia Station pink granite and pegmatite have been intimately injected into more or less hornblende gneiss (presumably gabbro), and much of the hornblende has been altered or recrystallized into green monoclinic pyroxene, some of which occurs locally in the form of coarse granular masses several inches across. Magnetite is variably abundant in all the rocks, but it is especially so in the coarser pegmatites and the silexite of later origin which occur as rather well-defined dikes.

On the ridge one and one-half miles northeast of Standish a very irregular pegmatite dike, with a maximum width of thirty feet and traceable for one hundred and fifty feet, lies in contact with gneissoid gabbro. The pegmatite is moderately coarse to very coarse and is very rich in magnetite, many masses of which are from one to three inches across. Some tongues of the pegmatite rich in magnetite cut across the foliation of the gabbro.

On Elbow Hill two miles east-northeast of Lyon Mountain village a pegmatite dike ten feet wide and thirty feet long is directly associated with a mixture of granite and gneissoid gabbro. This pegmatite is practically a silexite, being very rich in quartz and low in feldspar, and it contains much magnetite in masses up to several inches across. The magnetite and quartz appear to be of the same generation. Some of the more ordinary later pegmatites close by contain little or no magnetite.

In one of the ore pits near the western end of the main workings at Lyon Mountain a pegmatite dike from one to two feet wide and exposed for seventy-five feet rather sharply cuts intricately mixed pink granite and hornblende gneiss. This pegmatite carries little or no quartz, but it does contain some magnetite.

By the river one mile south-southeast of Moffitsville later pegmatite cuts intricately involved granite and hornblende gneiss,

the pegmatite containing bunches of green, monoclinic pyroxene and hornblende which look like inclusions up to five inches across. The pyroxene developed by recrystallization of some of the hornblende of the hornblende gneiss during the process of pegmatization for all stages, from bunches and lenses of pure hornblende, to mixtures of hornblende and pyroxene not sharply separated, to pure pyroxene, occurs in the pegmatite. Also, in thin section every stage in the transformation of the hornblende to pyroxene has been observed. This pegmatite carries some magnetite and in one portion scattering single crystals of hornblende up to one inch long, and in another portion crystals of pyroxene up to one-half of an inch long.

Aplite dikes.—Aplite dikes are locally developed often in considerable numbers in the coarse or Hawkeye type of granite. It is a striking fact that nowhere in the quadrangle were aplite dikes observed in the typical Lyon Mountain granite which contains such a profusion of pegmatites and silexites. Possibly this is because the Lyon Mountain granite is itself locally rather aplitic in character. Since the Hawkeye granite contains relatively few pegmatite and silexite masses, such could seldom be observed in their relations to the aplites in single outcrops. Few if any aplites occur in the granitic syenite or quartz syenite. It should here be recalled that the field evidence strongly points to development of the Lyon Mountain granite, Hawkeye granite, granitic syenite, and quartz syenite from a single intrusive magma in the Lyon Mountain quadrangle.

Nearly all the aplites of the quadrangle are in the form of more or less well-defined dikes which are very uniform in composition, consisting of white or light-gray potash feldspar, microperthite, and quartz with almost no accessory minerals. In a few cases dark minerals occur in moderate amounts.

Most of the aplite dikes by far lie more or less perfectly parallel to the foliation of the coarse granite, but a considerable number cut across the foliation at various angles. Not uncommonly the cross-cutting dikes are branches of those which are parallel to the foliation. Contacts of the aplites against the granite are rarely sharp, though the transition generally takes place within an inch or two. Some of the aplite dikes, more especially the wider ones,

exhibit good magmatic flow-structure foliation. No case of an aplite dike grading into pegmatite was observed, though one example of gradation to silexite was noted. The aplite dikes usually vary from one or two to several feet wide and ten to twenty-five feet long, but some are considerably larger.

The field evidence strongly indicates that all or nearly all the aplites developed during a very late stage of the consolidation of the Hawkeye granite magma, as shown by the common parallelism to the foliation and the lack of very sharp contacts. There is no evidence, such as that above presented, that any of the aplites formed as early as the earliest of the pegmatite and silexite masses, and there is positive evidence that some, and strong probability that many, of the latest pegmatites were intruded after the aplites. Considering the time then during which the pegmatite and silexite masses developed, the aplites are intermediate and the length of time for their development was distinctly shorter. Descriptions of a few selected examples will serve not only to show the nature of the evidence upon which the foregoing conclusions are based, but also to bring out certain other features of interest.

A fine display of aplite dikes may be seen on the ridge one-half of a mile southeast of Hawkeye post-office. Contacts against the typical coarse granite are not sharp, but the transition takes place within an inch. The dikes show all widths up to three feet. Most of them roughly follow the foliation of the granite, but some cut across at low angles and a few at high angles. One dike lies at right angles to the foliation for about fifteen feet and then gradually swings into parallelism with it. A few rods east of this locality some lenses of aplite a few feet long occur with somewhat sharper contacts against the granite. This suggests an earlier development of aplite masses, either as segregation masses or as dikes, which were pulled apart and somewhat strung out in the form of inclusions in the still moderately fluid magma. On the ridge one-sixth of a mile northeast of the first-named locality an aplite dike twelve to eighteen inches wide and exposed for forty feet cuts diagonally across the foliation of the coarse granite without sharp contacts. Almost exactly in its middle there are two masses of silexite fifteen feet long and a few inches wide, with no

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very sharp contacts against the aplite. This silexite resulted from differentiation practically in the place where it now occurs.

On the eastern summit of Howard Mountain an aplite dike about one foot wide lies parallel to the foliation of and grades into the coarse granite on one side, but it has a fairly sharp contact on the other, this latter contact evidently being a result of some magmatic flowage along the border of the aplite after its development.

On the hill one and one-half miles southwest of Sugarbush post-office a distinctly foliated aplite dike with a maximum width of fifteen feet and traceable for one hundred feet pinches out at one end and everywhere grades into the coarse granite within an inch.

At the top of Averill Peak a number of aplite dikes up to one foot wide lie in the coarse granite parallel to its foliation and without sharp contacts. Some ordinary pegmatites of the late series cut right across these aplites. Several aplite masses ten to twenty feet long occur as lenses without very sharp contacts against the granite.

On a spur of Lyon Mountain one mile east-southeast of its summit a number of aplite dikes from one to two feet wide mostly lie roughly parallel to the foliation of the coarse granite, but some cut across at various angles. These dikes carry some dark minerals, are without sharp contacts against the granite, and are usually foliated parallel to their borders. Several of them contain distinct inclusions of the coarse granite in the form of lenses one or two feet long, without sharp contacts against the aplite and parallel to its foliation. The granite must have been almost or quite solidified before the aplitic magma entered.

One-half mile north of the last-named locality one small aplite dike cuts another without sharp contacts against either aplite or coarse granite. Thus there were two distinct intrusions of aplite not far apart in time.

Conclusions regarding pegmatite, silexite, and aplite in the granites.—Some of the main conclusions from the foregoing observations are as follows:

1. The Lyon Mountain granite and the Hawkeye granite are believed to have developed from a single body of intruding magma.

2. The Lyon Mountain granite contains a great profusion of silexite and pegmatite masses, while the Hawkeye granite contains relatively few.

3. The Hawkeye granite contains many aplite dikes, but none at all was observed in the typical Lyon Mountain granite.

4. By far the greater number of the pegmatites, both the earlier and the later types, consist almost wholly of quartz and alkalic feldspar. With a few local exceptions minerals which indicate the former presence of mineralizers other than water vapor are practically absent.

5. Silexite masses began to develop, probably as segregation products, while the granite magma still possessed a very considerable degree of fluidity, and they continued to form probably both as segregation products and as dikes, until the inclosing granite almost, or possibly completely, solidified.

6. Pegmatite masses also began to develop well before the solidification of the magma, though probably not as early as the earliest silexite masses, and they continued to form until almost, or possibly complete, consolidation of the inclosing granite.

7. The silexite masses represent very siliceous facies of the pegmatitic development, gradations from nearly pure silica to ordinary pegmatite being not uncommon.

8. By far the greater number of the pegmatites, silexites, and aplites occur within the parent granites, though some also occur in the relatively small remnants of the rocks into which the granites were intruded.

9. The aplites were developed during a late stage of the magma consolidation, none as early as the earliest pegmatites and silexites, and probably none as late as the latest pegmatites. Some aplites cut others, thus proving intrusions distinctly different in time.

Authors of practically all the standard works on petrology definitely regard pegmatites as intrusions into the already solidified portions of the magmas from which they were formed. Iddings[1] says that pegmatitic liquid may be made to "flow into openings formed by the fissuring of completely solidified parts of the magma,

[1] J. P. Iddings, *Igneous Rocks*, I (1908), 272.

chiefly the outer portions." According to Harker,[1] "the pegmatite may in any case be regarded as representing the residual 'mother liquor' at the end of the process of crystallization." Pirsson[2] states that pegmatite dikes form "in the already solidified parts of the igneous mass." In an important paper on the origin of pegmatite Crosby and Fuller[3] say: "Pegmatite is the end product or final crystallization of the original magma." Brögger[4] considers certain Norwegian pegmatites as representing the last stage of the consolidation of the granite magma. Such statements as the preceding may hold for many of the pegmatites and silexites of the world, but the writer's conclusions (Nos. 4 and 5 above) regarding the pegmatites and silexites of the Lyon Mountain district are notably different, that is to say both pegmatite and silexite began to develop while the parent magma was still in a relatively highly fluid state.

It is also commonly stated or assumed that pegmatites and silexites always developed in the form of dikes. But from the evidence above presented for the Lyon Mountain district, it is concluded that many of the pegmatite and silexite masses, especially those of earlier origin, developed as magmatic segregation products because they formed while the inclosing granite was still magmatic with a considerable degree of fluidity, and it is difficult if not impossible to understand how pegmatite and silexite in the form of true dikes could have intruded such a magma.

For the comparatively few districts in which silexites have been carefully studied it is commonly held that where pegmatite and silexite have both developed from a granite magma the silexite solidified last. As Iddings[5] says: "The association of these quartz rocks with pegmatite is such that in many instances they appear to be portions of the magma segregated from the rest and the last to crystallize." Spurr[6] reaches the same conclusion after

[1] A. Harker, *The Natural History of the Igneous Rocks* (1909), p. 296.

[2] L. V. Pirsson, *Rocks and Rock Minerals* (1909), p. 175.

[3] W. Crosby and M. Fuller, *Amer. Geol.*, XIX (1897), 165.

[4] W. C. Brögger, *Zeit. für Kryst.*, XVI (1890).

[5] J. P. Iddings, *Igneous Rocks*, II (1913), 28.

[6] J. E. Spurr, *U.S. Geol. Surv., Prof. Paper 55* (1906), p. 115.

a careful study of the quartz of magmatic origin in the Silver Peak district of Nevada. In the Lyon Mountain district, however, the writer finds that silexite masses began to develop not only well before the consolidation of the parent granite magma, but also apparently even before the earliest of the pegmatites.

It is also a matter of common record that pegmatites are either absent from, or relatively uncommon in, their parent igneous body, while they are relatively abundant in the country rocks. Grout[1] has recently cited a number of the many well-known examples. In the Lyon Mountain district, however, pegmatite and silexite masses are extremely abundant in the parent granite, and they are certainly not more common in the relatively small portions of the intruded country rocks which still remain.

Finally many districts show ordinary pegmatite dikes close to or in the granite, and, traced outward into the country rocks, the pegmatites become more and more siliceous, being practically silexite dikes or quartz veins farthest out. As Pirsson[2] says: "Finally passing onward the solution phase might become more pronounced, only silica would be carried, and the dike turn into a quartz vein." Van Hise,[3] in the Black Hills, and Emerson,[4] in western Massachusetts, found pegmatite dikes in schist near granite, and farthest out silexite dikes or quartz veins. But in the Lyon Mountain district such a relationship does not hold, since typical pegmatites and silexites in many places occur side by side in the parent granite, and in some cases both form parts of individual dikes or segregation masses.

PEGMATITES IN THE GABBRO OF THE NORTH CREEK QUADRANGLE

Some years ago the gabbro masses of the North Creek quadrangle were discussed at considerable length by the writer.[5] The very common if not constant close association of pegmatites with

[1] F. F. Grout, *Econ. Geol.*, XIII (1918), 180–90.

[2] L. V. Pirsson, *Rocks and Rock Minerals* (1909), p. 180.

[3] C. R. Van Hise, *U.S. Geol. Surv., Mon. 47* (1904), p. 724.

[4] B. K. Emerson, *U.S. Geol. Surv.*, Folio 50, 1896.

[5] W. J. Miller, *Jour. Geol.*, XXI (1913), 160–80; *N.Y. State Mus., Bull. 170* (1914), pp. 26–28.

the gabbro was then mentioned, but no special study of the pegmatites was made. In 1918 the region was revisited, and the relations of the pegmatites to the gabbro were studied in detail. The gabbro nearly always occurs in the form of stocks or bosses with rounded or elliptical ground plans. The stocks range in length from a few rods to about a mile and in width up to three-fourths of a mile. That most if not all of the gabbro stocks are younger than the syenite-granite series is proved by the many observed sharp contacts often crossing the foliation of the syenite or granite, by many inclusions of syenite and granite in the gabbro, and by some dikes of gabbro which extend into the syenite-granite series.

The field evidence strongly points to the mode of occurrence of the gabbro as pluglike or pipelike forms with nearly vertical boundaries. Much of the gabbro is of the quite typical sort, consisting chiefly of basic plagioclase, some orthoclase, hornblende, and hypersthene, together with almost constant small amounts of ilmenite (or magnetite), biotite, garnet, and pyrite, and some other accessory minerals. An ophitic texture is often well exhibited. Many of the stocks have foliated portions, especially the borders, which are hornblende gneiss or amphibolite.

The pegmatites are mostly coarse-grained, consisting chiefly of potash feldspar and quartz, but with plagioclase important in some cases, muscovite and black tourmaline usually present, and biotite and hornblende not rare. Practically no other minerals occur. The masses of pegmatite exist in all sizes up to two hundred or more feet long and fifty or more feet wide.

Very few of the many conspicuous bodies of pegmatite of the kind just described were observed apart from masses of gabbro in the North Creek quadrangle, and possibly even these few may not be real exceptions, because the adjacent rocks are not always wholly known on account of lack of exposures. Pegmatites of any kind are relatively scarce in the syenite-granite series. Since most or all of the gabbro stocks are younger than the syenite-granite, and since so many of the coarse, acidic pegmatites either cut the gabbros or are at least genetically related to them (see below), it follows that such pegmatites must be distinctly younger

than the syenite-granite series. Pegmatites seldom if ever occur well within the larger areas of gabbro, and it seems that they formed as satellites of the gabbro mostly in the marginal portions of the stocks and to some extent at least in the closely adjacent rocks.

There are two features of special interest regarding these pegmatites: first, that they are satellitic developments of rather

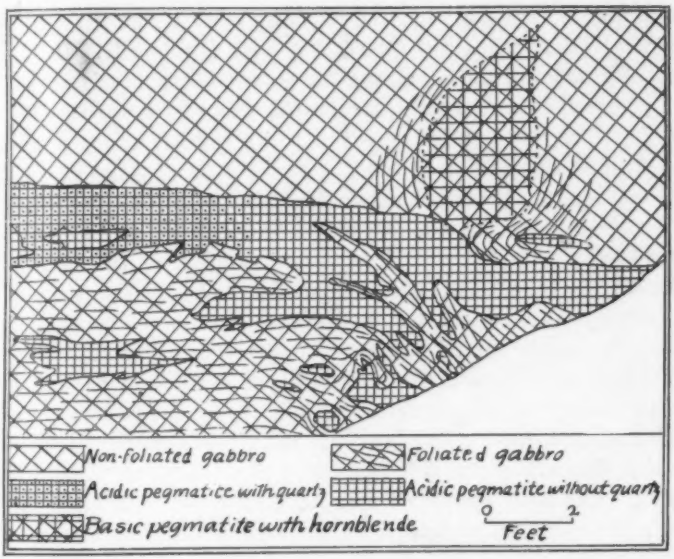

FIG. 7.—Sketch showing the relations of several facies of pegmatite to gabbro at the northeastern edge of the stock on the hill one mile south-southeast of the Glen in the North Creek quadrangle.

basic gabbro, and, secondly, that the evidence strongly points to the development of many of them while the parent magma still possessed a considerable degree of fluidity. The following descriptions and figures of selected examples will serve to make clear the principal phenomena of the pegmatites in their relations to the gabbros.

One of the best places in the North Creek quadrangle to study the relation of pegmatite to the typical gabbro is at the top of the

hill one mile south-southeast of the Glen. The gabbro stock, which is one-fourth of a mile long, shows a number of pegmatitic satellites, and that it is younger than the surrounding granite is proved by several inclusions of the latter. Figure 7 illustrates the relations of several facies of the pegmatite to the gabbro near the northeastern edge of the stock. Crystals in any of the pegmatite seldom reach lengths of an inch. The acidic pegmatite with quartz carries biotite, and it grades perfectly into the rather acidic pegmatite without quartz but with hornblende. In both of these facies of the pegmatite the chief feldspar is oligoclase to oligoclase-albite. Contacts against the gabbro are usually rather sharp. The more basic pegmatite, which consists chiefly of basic plagioclase and hornblende with some magnetite, shows no sharp contact against either the acidic pegmatite or the gabbro. That the various facies of the pegmatite formed while the gabbro magma was still in a distinctly fluid condition is considered to be proved, not only by the presence of well-defined inclusions of the pegmatite mostly parallel to the magmatic flow-structure of the gabbro, but also by the strong tendency of the fluxion structure of the gabbro to wrap around the inclusions and to conform to the sides of the large body of pegmatite. Quite clearly the molten gabbro intruded and more or less broke up the already consolidated pegmatite which had probably developed as a magmatic segregation mass. The basic pegmatite may have developed somewhat later than the other, as suggested by the lack of anything like sharp contacts against the gabbro, but even this pegmatite formed while the gabbro was still fluid enough to develop a fluxion structure alongside the pegmatite.

Near the middle western edge of the same gabbro stock a pegmatite mass, with a maximum width of twenty-five to thirty feet and an exposed length of about one hundred feet, shows relations notably different from those on the opposite side of the stock above described. Some of the features are brought out by Fig. 8. Toward one side of the general body of pegmatite a mass of practically pure silica (silexite) has imbedded in it many rather imperfect crystals of black tourmaline which mostly range in length from one to ten inches. This small mass is surrounded by very coarse pegmatite made up chiefly of potash feldspar and quartz with a little tour-

maline, the feldspars reaching lengths of a foot or more. Inclosing both masses just mentioned is a body of coarse pegmatite, which is the most abundant facies of the rock. The feldspar all seems to be orthoclase in crystals, with maximum lengths of six or eight inches. Quartz is abundant, and hornblende crystals up to several inches long are fairly common. There are also exceptionally fine graphic intergrowths of tourmaline and quartz in masses from a few inches to a foot or more across (Fig. 6C). Along one side of the coarse pegmatite there is a zone roughly five or six feet wide of only moderately coarse pegmatite which consists chiefly of potash feldspar and quartz with some acidic plagioclase and biotite. Adjacent to this moderately coarse pegmatite and forming the outside of the whole mass of pegmatite on one side is a zone several feet wide of moderately coarse pegmatite made up very largely of plagioclase which contains some microcline as graphic intergrowths and a little quartz. This plagioclase zone merges into the true gabbro through a zone about a foot wide. None of the five facies of pegmatite just described are at all sharply separated from each other, and they are very clearly phases of a single pegmatite body. The relation of the pegmatite to the gabbro on the opposite side of the whole body of pegmatite is not so well shown, but there appears to be a gradation within an inch or two. On either side of the pegmatite body the gabbro is non-foliated. Similar relations to the gabbro are exhibited where the pegmatite body extends fifty feet northeastward, ending in broad tongues in the gabbro. There, however, the plagioclase zone is seven or eight feet wide, and it contains considerable quartz and some biotite. One mass of gabbro five feet across is surrounded by pegmatite with a fairly sharp contact on one side and a gradation on the other.

The assumptions that this whole body of pegmatite was a distinctly later satellitic development of the gabbro than that above described as occurring on the opposite side of the same stock, that the gabbro must have been almost or quite solidified before it formed, and that the five facies of the pegmatite were probably formed by some sort of differentiation practically in the place of their present occurrence are evidenced by the following facts: gradation of the borders of the pegmatite into the gabbro,

an inclusion of the gabbro in the pegmatite, lack of magmatic flow-structure foliation in the gabbro near the pegmatite, and perfect gradation from one facies of the pegmatite into another.

Along the northwestern side of the same gabbro stock there are several small pegmatite masses, one with fairly sharp contacts and the other without. Also a number of rather rounded masses of basic pegmatite (chiefly plagioclase and hornblende) from one to several feet across appear to be inclusions, with fairly sharp contacts, in foliated gabbro. Such pegmatite must have formed

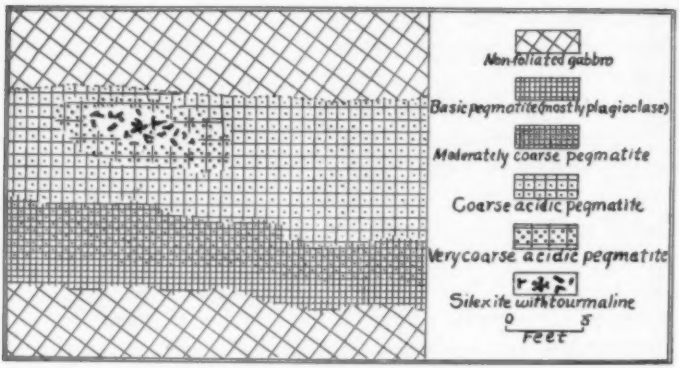

FIG. 8.—Sketch showing several facies of pegmatite in the gabbro at the western edge of the stock on the hill one mile south-southeast of the Glen in the North Creek quadrangle.

while the gabbro was still molten. A few rods farther north a small dike of acidic pegmatite with rather sharp contacts has an aplitic offshoot three inches wide which bears off abruptly for twelve feet into non-foliated gabbro, with fairly sharp contacts against the latter.

On the southern side of the small stock one and one-fourth miles north of the Glen several moderately coarse acidic pegmatite masses from three to twelve feet long lie in the gabbro, with fluxion structure of the latter parallel to the borders of the pegmatite, but only close to them. Contacts against the gabbro are rather sharp. Well within the stock several small inclusions of the country rock (granite) also lie in the gabbro parallel to a magmatic

flow-structure foliation of the latter. Clearly, then, these acidic pegmatites are not only satellites of the gabbro but also formed, probably by magmatic segregation, well before the gabbro magma was consolidated. Another body of pegmatite about six feet wide in this gabbro grades into a mass of practically pure silica (silexite) four feet long.

A large body of pegmatite exposed for two hundred and fifty feet lies on the east side of the gabbro stock near the top of the hill three and one-half miles south-southeast of Chestertown. This pegmatite is mostly orthoclase and quartz in masses up to a foot or more across, together with considerable muscovite, biotite, and tourmaline in masses up to several inches across. In an old mine pit a moderately coarse facies of this pegmatite containing some plagioclase is intricately involved with a highly foliated feldspar-biotite schist phase of the gabbro which grades perfectly through a fine-grained foliated gabbro into normal, medium-grained, non-foliated gabbro. The zone of mixed rocks, which is forty to fifty feet wide, contains many long lenses, strips, and irregular masses of pegmatite arranged roughly parallel to the fluxion-structure foliation of the schistose facies of the gabbro. Evidently this pegmatite, which developed as an early satellitic facies of the gabbro magma, was more or less broken up and involved with the yet molten gabbro.

Two miles southeast of Chestertown a gabbro stock with highly foliated facies not only contains inclusions of, but also sends dikes into, the granite porphyry country rock. At its north end the foliation of the gabbro perfectly conforms to the rather irregular side of a large mass of pegmatite, which latter is cut by well-foliated, fine-grained gabbro in the form of dikes up to eight feet long, one of these dikes ending in a feldspar-biotite schist. A dike of similar fine-grained gabbro not over six inches wide cuts the granite for thirty feet. In this case it seems certain that the pegmatite must have formed well before the solidification of the parent gabbro, because the pegmatite was intruded by the molten gabbro.

At the top of Hackensack Mountain near Warrensburg a dike of the gabbro clearly cuts syenite, and the fluxion structure of the gabbro conforms to the borders of a small mass of included pegmatite.

Conclusions regarding pegmatites associated with gabbro.—From many occurrences like the examples above described it is concluded that acidic masses ranging from pegmatite rich in potash feldspar and quartz, with or without tourmaline, to pegmatite which is mostly potash feldspar, to pegmatite rich in acidic plagioclase with or without quartz, to basic pegmatite which consists either of basic plagioclase and hornblende or nearly all basic plagioclase, to aplite dikes, and even to nearly pure silica (silexite), developed as satellites of the stocks of normal gabbro. It is also concluded that the development of pegmatite began while the gabbro was still notably fluid, and that it continued until it had almost or completely solidified. Accordingly it seems necessary to regard the earlier-formed pegmatite masses to have developed as segregation masses rather than as true dikes.

It is possible, as maintained by Grout[1] for the Duluth gabbro, that some development of pegmatite may have taken place before the beginning of crystallization of the gabbro magma, but the evidence in the North Creek district is not conclusive. Many of the North Creek pegmatites differ from the Duluth pegmatites in one important respect, namely, that they developed as satellites of the gabbro late in the stages of magma consolidation, some of them probably even after complete solidification.

Such a profuse development of so many kinds of pegmatites from gabbro bodies is not in agreement with the commonly held view as stated by Weinschenk, who says that pegmatites "are relatively rare with plagioclase rocks," and "the more basic the plutonic rock, the simpler are its satellites."[2]

Grout's work on the origin of the pegmatites of the Duluth gabbro and the writer's work on the origin of the pegmatites of the granites of the Lyon Mountain district and of the gabbro of the North Creek district clearly show that many of the pegmatites of those districts are not, as is so commonly stated for other regions, to be regarded as intrusions into already solidified portions of the magma from which they were derived.

[1] F. F. Grout, *Econ. Geol.*, XIII (1918), 190–92.

[2] E. Weinschenk-Johannsen, *Fundamental Principles* (1916), p. 142.

WAS THERE A "CORDILLERAN GLACIER" IN BRITISH COLUMBIA?

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In August, 1888, the late Dr. G. M. Dawson, then assistant director of the Geological Survey of Canada, published in the *Geological Magazine* a paper entitled "Recent Observations on the Glaciation of British Columbia and Adjacent Regions," in which he states that

> the examination of this northern region may now be considered to have established that the main gathering-ground or *névé* of the great Cordilleran Glacier of the west coast, was included between the fifty-fifth and fifty-ninth parallels of latitude in a region which, so far as explored, has proved to be of an exceptionally mountainous character. It would further appear that this great glacier extended, between the Coast Range and the Rocky Mountains, southeastward nearly to latitude 48°, and northwestward to latitude 63°, or beyond, while sending also smaller streams to the Pacific Coast.

In a subsequent paper[1] published in the *American Geologist* for September, 1890, he writes of his conclusions derived from his geological explorations in British Columbia as follows:

> Having thus surrounded the area of this great glacier, it was proposed to name it the *Cordilleran Glacier* in order to distinguish it from the second and larger ice-cap by which the northeastern part of the continent was at the same period more or less completely covered.
>
> The Cordilleran Glacier, as thus defined, had, when at its maximum development, a length of nearly 1,200 miles. The main gathering-ground or *névé* of the *mer de glace* was contained approximately between the fifty-fifth and fifty-ninth parallels of north latitude, that part of the ice which flowed northwestward having a length beyond these limits of 350 miles, that which flowed in the opposite direction a length of about 600 miles.

In another place in the same paper he says:

> The width of this (Cordilleran) zone is about 400 miles, and on one side of it lies the wide area of the Great Plains, on the other the Pacific

[1] "On the Glaciation of the Northern Part of the Cordillera," by George M. Dawson, *Am. Geol.*, September, 1890, pp. 153–62.

Ocean. . . . . This part of the Cordillera of the West was, in the Glacial period, covered by a great confluent glacier-mass.

In a longer paper, published in the same year in the *Transactions of the Royal Society of Canada* (Vol. 8, Sec. 4, pp. 3–74), he reiterated his belief in this glacier, and gave a map showing its extent from the Yukon Territory down to an irregular line south of latitude 49°.

Last summer my mining duties called me to British Columbia and I traveled by the Grand Trunk Pacific Railway, stopping off at Prince George, which is on the interior plateau of the province, just south of latitude 54° north, and 80 or 90 miles in a direct line southwest of the eastern range of the Rocky Mountains. Its elevation is 1,862 feet above sea-level. From Prince George I descended the Fraser River, a distance of about 70 miles in a straight line, to Quesnel, which lies at an elevation of 1,570 feet above sea-level, and from there went eastward 50 miles to the old gold-mining district of Cariboo, which is at an elevation of about 4,000 feet above sea-level. During this time I was in the middle of the region of which Dr. Dawson writes "that the ice reached a general thickness of 2,000 to 3,000 feet above even the higher tracts of the plateau, while it must have attained a thickness of over 6,000 feet above the main river valleys and other principal depressions of the surface."[1] It was therefore natural for me to look for evidence of intense ice action such as may be seen in valleys cutting through or descending from the Coast Range of this western province, but such evidence was conspicuously absent.

The Fraser River flows in a direction a little east of south in the bottom of a great wide valley, with high rugged mountains in the distance both to the east and west, this valley being simply the lowest part of the great interior plateau of British Columbia.

On the eastern side of this valley or plateau, and on the western slopes of the mountains which define its eastern rim, is the Cariboo district in which marvelously rich placer mines were discovered and worked in the early sixties of last century. The rocks composing the mountains are pre-Cambrian or Cambrian sericitic and chloritic schists. Deep, narrow valleys carry streams

[1] *Am. Geol.*, September, 1890, p. 155.

down from the sides of these mountains, and gold was found in gravel, and in bedrock beneath the gravel, in the bottom of these valleys. Much of the gold occurred in preglacial, or Pliocene, gravels that had been buried under a bed of massive bowlder clay, holding many glaciated pebbles and bowlders. Immediately under the bowlder clay is often a stratified deposit of fine quicksand or slimy silt, locally known as "slum," which is a sericitic silt that was washed from the decomposed surface of the rock by glacial streams before the advancing glaciers themselves had reached so far down the valleys.

It was in the latter part of the month of May, and snow still covered the tops of the ridges when I was in the district. Though I saw many rock exposures, but one, a quartz vein, had preserved glacial grooves and striae. This vein was on the north side of the valley of Lightning Creek, one of the principal streams of the district, and 1,000 feet above the bottom of the valley, or 4,800 feet above the sea. The markings ran N. 45° W. (true), which was roughly parallel to the course of the valley, and the direction of motion of the ice was quite clearly indicated by some rock cliffs in the vicinity.

As Lightning Creek Glacier moved down the valley it removed loose material from the lateral slopes and deposited some of it in the tributary gulches, thus covering the bottoms and the upper sides of these gulches. After the glacier had retired and disappeared, the drainage of the country was re-established in the same gulches as before, but on top of the bowlder clay left by the glacier and farther down the stream, so that when the gold miners wanted to find the deeper preglacial channels of the gulches they were obliged to explore for them in an easterly direction or up the main stream. In the valleys of Slough Creek and Willow River similar conditions prevail with regard to the lateral gulches, as doubtless local valley glaciers also moved westward and northwestward down these valleys.

Well-marked moraines are present in many of the valleys, conspicuous among them being a large hilly moraine in the valley of Slough Creek below Jack-of-Clubs Lake, and a similar lumpy, pitted moraine in Lightning Creek Valley below Stanley.

Hydraulic operations have exposed excellent sections of bowlder clay in a number of places, and there is only one bowlder clay, namely that of the valley glaciers. I am quite satisfied that the only glaciation that has ever prevailed in this country was the local glaciation from the adjoining mountains.

After spending a few days in the district we returned westward along the wagon road to Quesnel. This road follows the bottom of the valley of Lightning Creek Valley for 15 miles or more, then crosses a sand and gravel plain, after which it descends into the valley of Cottonwood River. In this distance very little rock is exposed, and there is but little evidence of glaciation, except one or two local moraines. On Cottonwood River, near the bridge, basic igneous rocks occur, probably cutting the Oligocene conglomerates, but I was unable to find any evidence of glaciation on them.

Five or six miles farther west the road crosses a lumpy moraine dotted with small lakes, and a short distance farther west it skirts a low rounded hill of porphyritic red granite, the surface of which shows strong glacial markings running N. 15° W., the direction being clearly indicated by the rounded stoss and broken lee sides of the knolls. As seen from this hill the view to the southward is up the wide valley of the Quesnel River, and it is evident that the glacier which formed the markings on the rock descended this valley. The moraine just crossed was also doubtless formed by the same glacier. Though a careful examination was made of the exposed rock no scoring or polishing, other than that caused by the one glacier, could be found. From this rocky hill, which is at an elevation of 3,200 feet above the sea, our course was westward for about 14 miles to the village of Quesnel on the east bank of Fraser River. Throughout this distance no rock was seen, the surface being mostly composed of sand and gravel arranged in wide terraces, though bowlder clay was occasionally recognized.

Fraser River itself, between Prince George and Quesnel, is a large stream which has cut out a winding, gorgelike valley. Above Quesnel as far as Cottonwood Canyon the banks are steep, often almost vertical, and are composed of horizontally stratified conglomerate and soft sandstones of Miocene(?) age.

As seen from the river the banks rise to a horizontal plain, which extends eastward and westward for an indefinite distance. Here and there as many as five different terraces might be counted one above the other on the insides of some of the bends, but altogether the valley has a very juvenile appearance. It is clearly preglacial, for bowlder clay may be seen resting on its sloping sides and lying on some of its terraces. In some places, where it has been partly filled by bowlder clay during the glacial period, the channel has been re-excavated to about its previous depth. Near the top of its banks beds of bowlder clay are here and there interstratified with layers of sand, some of which have been crumpled, giving evidence that glaciers from the mountains to the east or west descended into lakes which then existed in the bottom of the valley, and squeezed up the beds of gravel and sand that had just been deposited in those lakes.

Above Cottonwood Canyon the valley maintains the same general character as below it, with steep banks rising to the adjoining plain, but in addition to the Miocene(?) conglomerates, etc., schistose rocks, similar to the Cariboo schists, outcrop here and there, while at still other places the banks are composed of stratified sand or clay of glacial or postglacial age.

It is impossible to imagine such a winding, gorgelike valley as this of the Fraser River, with its short curves, and with the relatively sharp angles where its steep sides meet the surrounding plain, continuing to exist after a great continental glacier many thousands of feet in thickness has passed along it. Its appearance is quite different from that of such of the British Columbia valleys as have undoubtedly been occupied by great glaciers. On the contrary it has a strong topographic resemblance to the Yukon Valley near Dawson City, where the river flows through an unglaciated part of the Yukon Plateau, which is a northern continuation of the interior plateau of British Columbia. Here glaciers formerly descended from the Coast Range of mountains eastward to the interior plateau, and others descended from the Rocky Mountain range westward to the same plateau, but as they did not meet they left an unglaciated area between them. In the Fraser Valley glaciers also descended from the mountains to the east

and to the west, toward the middle line of the intermediate plateau or valley. For the most part they ended before they reached the present river channel, but in other cases they discharged into great lakes, in which the white silts which form such conspicuous cliffs near Prince George were deposited.

The glaciers always moved inward from the mountains which form the sides of the valley toward its median line, and the ice was thicker on the mountains than in the valley. At no time was this portion of the interior plateau covered by a glacier of the extent and thickness indicated by Dr. Dawson, namely 6,000 feet deep over the lower land, from which the ice moved outward in all directions.

This conclusion is in accord with the observations of the late G. S. Malloch, of the Geological Survey of Canada, who, in 1909, made a geological examination of the upper part of the Fraser River from Tête Jaune Cache down to Prince George. He states that

> bowlder clay occurs at different points along the river. These deposits were formed by two sets of glaciers, the first of which descended into the Interior Plateau from the mountains to the east, and the second from those to the west. The drift of the latter is characterized by the presence of granite fragments from the Coast Range, and volcanic rocks from the western part of the plateau. On the other hand, that from the east contains fragments of older rocks, and it alone is seen on the river from Tête Jaune Cache to Giscome Rapids, where it is overcapped by the drift from the west.[1]

These observations therefore exclude the possibility of the existence of a great longitudinally moving Cordilleran Glacier on this portion of the interior plateau in latitude 54°, and my own observations show that it was absent as far south as Quesnel in latitude 53°. From there to the southern end of the glacier as defined by Dr. Dawson is only a little more than 300 miles, and even if the whole of the country throughout this distance were covered by ice it would not fulfil the idea of a great continental glacier. As to what were the ice conditions north of Prince George, between latitude 54° and 63°, we have not yet sufficient information available to enable us to decide.

[1] *Geol. Surv. Can. Sum. Rep. for 1909*, Ottawa Govt., 1910, p. 128.

Reviews

Geology and Mineral Resources of Kenai Peninsula, Alaska. By G. C. Martin, B. L. Johnson, and U. S. Grant. U.S. Geol. Surv., Bull. 587, 1915. Pp. 243, pls. 38, figs. 43.

This volume is a summary of what is known of the geology and mineral resources of the Kenai Peninsula, including both the results of the early investigations and the hitherto unpublished work of the present writers. In an introductory chapter Martin summarizes the geology of the general region; the succeeding chapters are devoted to a more detailed discussion of its several parts. The relations of highly folded pre-Tertiary sediments and associated lavas and intrusives of the Kenai Mountains are as yet imperfectly known. Rocks definitely assignable to the Triassic and to the Jurassic are known over limited areas, but the great bulk of the slate and graywacke series has not been differentiated. It may include upper Paleozoics and possibly some Mesozoics younger than the Jurassic. The Sunrise group of earlier writers probably represents the upper part of this series and seems to be more nearly equivalent to the Orca group than to the Valdez group in the Prince William Sound region. The only Tertiary beds of the Kenai Peninsula are those of the non-marine Kenai formation.

The gold lodes of the northern Kenai Peninsula are described by B. L. Johnson. The deposits are of three general types—fissure veins, stringer lodes, and mineralized silicic dikes. The veins occur in two distinct sets, standing approximately at right angles to each other and dipping at high angles. Both sets of fractures are ore-bearing and of about the same age. Their average thickness is between 2 and 2½ feet. The present known vertical range of these veins is about 5,000 feet. Of minor importance are the stringer lodes, characteristically developed in the slates and graywackes parallel to the cleavage and bedding planes. Only slightly mineralized dikes have been discovered thus far. The mineralogical composition of the veins is simple and indicates deep-seated conditions of origin. Quartz is the predominant gangue mineral, Calcite is generally present and albite locally. Arsenopyrite, galena, sphalerite, and pyrite are the characteristic sulphides, arsenopyrite being most abundant. Chalcopyrite and pyrrhotite are less common.

Molybdenite is present at two localities. The gold occurs in the native state. The mineralization was subsequent to the intrusion of the Mesozoic granite batholiths and the related stocks and dikes. The depositing solutions were probably residual emanations from these magmas. The gold lodes of the Kenai Peninsula correspond, therefore, both in age and general association, with the similar deposits elsewhere in Alaska.

H. R. B.

Field Geology. By FREDERIC H. LAHEE. New York: McGraw-Hill Book Co. 12 mo, pp. xxiv+508. $3.00.

This work is divisible into two parts: an empirical treatment of geologic phenomena (twelve chapters), and a compilation of field and office methods (six chapters).

The first part covers well-nigh the whole field of phenomenal geology and will find its greatest usefulness among undergraduate students. For working geologists the most valuable matter will be found in the chapters on "Geologic Surveying," "Modes of Geologic Illustration," "Geologic Computations," and "Preparation of Geologic Reports," and in appended tables. One wishes that more of the field and office methods contributed in the last few years to economic geology were presented.

In carrying out the scheme of empirical treatment of phenomena the author has constructed many carefully analyzed "keys" or tables, like those of mineralogical and botanical texts. The reviewer has tried out the work in two field courses, placing it in the hands of the students simply as a reference, and has found it very valuable, though the students did not voluntarily make use of the "keys." These may find their usefulness among beginners without field association with more experienced men.

The author has digested pertinent matter from such works as Leith, *Structural Geology;* Leith and Mead, *Metamorphic Geology;* Grabau, *Stratigraphy;* Lindgren, *Mineral Deposits,* etc., and presents valuable material from the field handbooks of Hayes, of Farrell, and of Geikie. Important contributions to periodical literature have also been drawn upon.

The book is one of the McGraw-Hill series of limp-cover handbooks, with narrow margins and rounded page corners. Its 500 pages of thin paper will prove no burden in the pocket.

J. H. B.

Recent Publications

—Rastall, R. H. Agricultural Geology. [Cambridge: University Press, 1916.]

—Rio de Janeiro, Archivos do Museu Nacional do. Vol. XVIII. [Rio de Janeiro, Brazil, 1916.]

—Rogers, G. S. Chemical Relations of the Oil-Field Waters in San Joaquin Valley, California. Preliminary Report. [U.S. Geological Survey, Bulletin 653. Washington, 1917.]

—Rose, B. Wood Mountain–Willowbunch Coal Area, Saskatchewan. [Canada Department of Mines, Memoir 89, No. 1138, Geological Survey, Geological Series, No. 75. Ottawa, 1916.]

—St. Clair, S. Clay Deposits near Mountain Glen, Union County, Illinois. [Illinois Geological Survey, extract from Bulletin 36. Urbana, 1917.]

—Sauer, C. O. Geography of the Upper Illinois Valley and History of Development. [Illinois Geological Survey, Bulletin 27. Urbana, 1916.]

—School of Mines and Metallurgy, University of Missouri, Bulletin of. Technical Series, Vol. III, No. 2. Studies on the Origin of Missouri Cherts and Zinc Ores. [Rolla, November, 1916.]

—Schrader, F. C., Stone, R. W., and Sanford, S. Useful Minerals of the United States. [U.S. Geological Survey, Bulletin 624. Washington 1917.]

—Schwennesen, A. T. Ground Water in San Simon Valley, Arizona and New Mexico. With a Section on Agriculture by R. H. Forbes. [U.S. Geological Survey, Water-Supply Paper 425-A. (Contributions to the Hydrology of the United States, 1917, pp. 1–35.) Washington, 1917.]

—Smith, G. E. Primitive Man. Proceedings of the British Academy, Vol. VII. [London: Oxford University Press, 1917.]

—Smith, J. E. A Laboratory Guide for Beginners in Geology. [Chapel Hill, N.C., 1917.]

—Spencer, L. J. The World's Minerals. With an Appendix by W. D. Hamman. [New York: Frederick A. Stokes Co., 1916.]

—Strahan, A., and Others. The Investigation of Rivers. Final Report. The Royal Geographical Society. [London: Kensington Gore, S.W. 1916.]

—Tolman, C. F., Jr., and Rogers, A. F. A Study of the Magmatic Sulfid Ores. Leland Stanford Junior University Publications. University Series. [Stanford University, California, 1916.]

—Udden, J. A., Baker, C. L., and Böse, Emil. Review of the Geology of Texas. [Bulletin of the University of Texas, 1916. No. 44. Austin.]

—Udden, J. A., and Bybee, H. P. The Thrall Oil Field. Also "Ozokerite from the Thrall Oil Field," by E. P. Schoch, and "The Chemical Composition of the Petroleums Obtained at Thrall, Texas," by E. P. Schoch and W. T. Read. [Bulletin of the University of Texas, 1916. No. 66. Bureau of Economic Geology and Technology. Austin, 1916.]

—United States Coast and Geodetic Survey, Centennial Celebration of the, April 5 and 6, 1916. [Washington, 1916.]

—Washington Academy of Sciences, Journal of the. Vol. VI. [Baltimore: Waverly Press, 1916.]

———. Vol. VII, 1917.

—Washington University Studies. Vol. III. Part I, No. 1 (July, 1915), No. 2 (January, 1916). Part II, No. 2 (April, 1916). Vol. IV. Part I, No. 1 (July, 1916). [St. Louis.]

—WATSON, THOMAS L., AND BEARD, R. E. The Color of Amethyst, Rose, and Blue Varieties of Quartz. No. 2220. From the Proceedings of the United States National Museum, Vol. LIII, pp. 553–63. [Washington, 1917.]

—West Virginia Geological Survey. County Reports, 1917. Braxton and Clay Counties. With 4 maps, showing topography, general and economic geology, of each county. [Morgantown, 1917.]

———. (I. C. WHITE, State Geologist, assisted by R. V. HENNEN, D. B. REGER, and R. C. TUCKER.) Map of West Virginia showing coal, oil, gas, iron ore, and limestone areas. [Morgantown, 1917.]

———. (I. C. WHITE, State Geologist, assisted by R. V. HENNEN and R. C. TUCKER.) Map of West Virginia showing railroads. [Morgantown, 1917.]

—Western Australia Geological Survey. Annual Progress Report of the Geological Survey for the Year 1915. With an index map. [Perth, 1916.]

———. General Index to Reports, 1870–1910. Bulletin 60. [Perth, 1916.]

—WHERRY, E. T. Glauberite Crystal-Cavities in the Triassic Rocks of Eastern Pennsylvania. From the *American Mineralogist*, Vol. I, No. 3, pp. 37–43. September, 1916.

———. Soil Chemistry. A Chemical Study of the Habitat of the Walking Fern, *Comtosorus rhizophyllus* (L.) Link. From the Journal of the Washington Academy of Sciences, Vol. VI, No. 20. December 4, 1916.

—WHERRY, E. T., AND BROWN, G. V. An American Occurrence of Miloschite. Reprinted from the *American Mineralogist*, Vol. I, No. 4, pp. 63–67. October, 1916.

—Wisconsin Academy of Sciences, Arts, and Letters, Transactions of the. Vol. XVIII, Part II. [Madison, 1916.]

—Yorkshire Geological Society, Proceedings of the. New Series, Vol. XIX, Part III, pp. 75–253. [Leeds: The University, 1916.]

—YOUNG, L. E. Surface Subsidence in Illinois Resulting from Coal Mining. Illinois Coal Mining Investigations, Co-operative Coal Mining Series, Bulletin 17. [Illinois Geological Survey. Urbana, 1916.]

—YOUNG, L. E., AND STOEK, H. H. Subsidence Resulting from Mining. Illinois Coal Mining Investigations, Co-operative Agreement, Bulletin 91. Engineering Experiment Station, University of Illinois Bulletin, Vol. XIII, No. 49. [Urbana, 1916.]